Space Weather Report

IRIS Challenge: Tracking a Solar Storm

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BUCHAREST | ROMANIA

Contents

Introduction 2

Chapter I – Sunspot Regions 3

- Data Collection Sheet #1 13

Chapter II – Storm Signals 16

- Data Collection Sheet #2 25

Chapter III – Magnetosphere 27

- Data Collection Sheet #3 31

Chapter IV – Auroras 33

- Data Collection Sheet #4 37

Results 39

About 40

References 41

"I see no shadows," saith the Sun
Yet he casts them every one.

George Iles

The Sun – we owe our lives to this huge ball of plasma.

Let us imagine how the Solar System would look like without the Sun. Let us also assume that the Earth (and all the other planets in our system) were, somehow, created (which is impossible). How would they behave? Right now, the only thing keeping our planet from wildly flying through space is the Sun's gravitational pull. Without that, would all the planets come to a standstill? Would they all crash into Jupiter? What would happen without the Sun keeping us in place?

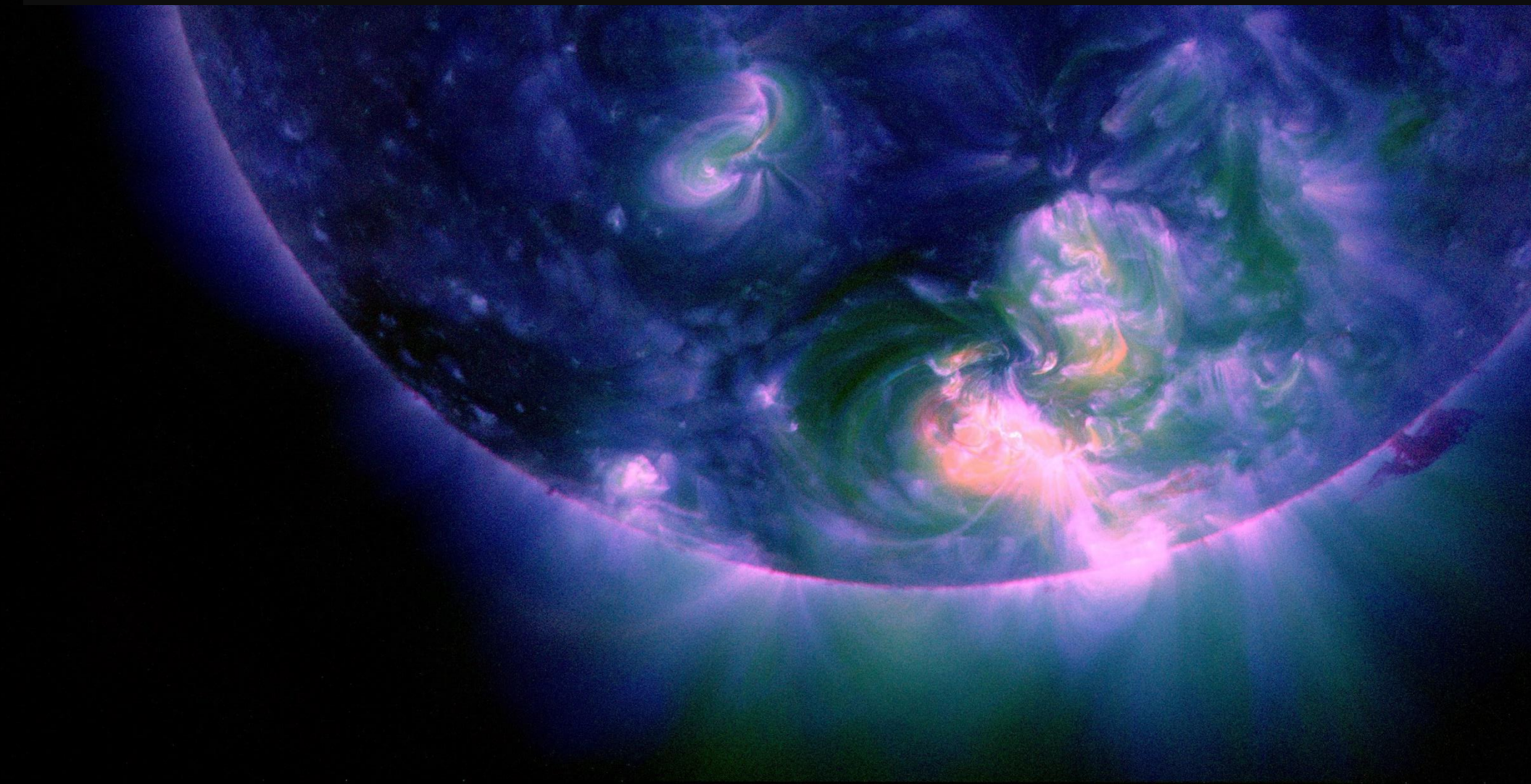
The Earth would be a cold, dark place. Literally. Because of the lack of light, vegetation would be absent. Furthermore, the 400C° temperatures would kill any form of life in less than a few years.

However…

…we should never forget that the Sun holds the power of destroying us in a split second. A ten percent increase in the global temperature is all it takes to wreak havoc in the world. One stronger than average solar storm is enough to shut down all our communication.

The Sun is currently entering a solar maximum, reaching the highest levels of solar activity in its eleven years cycle. Therefore, we can expect a high number of solar events such as sunspots, coronal mass ejections, coronal holes, loops and storms of varying intensities. In order to further our understanding of how the Sun works and how its activity affects the people of Earth, our team has taken over the task of collecting and analyzing data, with the purpose of putting together our own **Space Weather Forecast,** *For the Benefit of All*. Here, you will also find a link to the movie in which, working as a team, we stage a live weather forecast. We would also like to thank everyone who helped us during the making of this project.

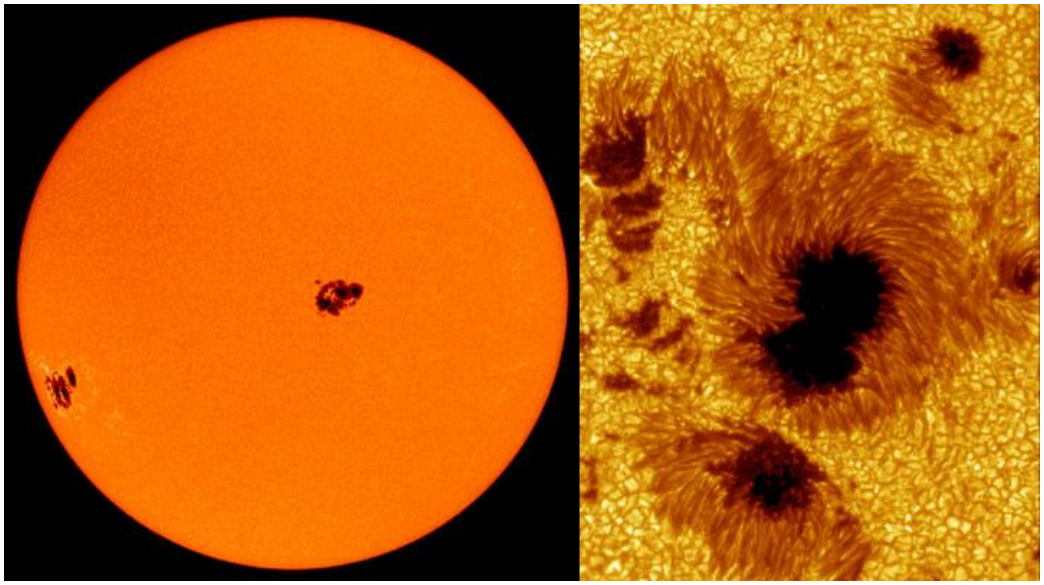
SUNSPOTS



CHAPTER I – SUNSPOT REGIONS

Introduction

One of the most interesting phenomena related to our Sun is, without a doubt, the appearance of large, dark spots on its photosphere. These regions are called *sunspots* and their dark color comes from the high contrast with the surrounding areas of the Sun. Sunspots are caused by intense magnetic activity and are connected to a number of other phenomena (solar flares, coronal mass ejections). Some theories have shown that they may even be affected by Jupiter's magnetic field. Therefore, monitoring the number and position of active sunspots, one is able to draw conclusions in regards to the Sun's behavior (and how it may influence the space weather).

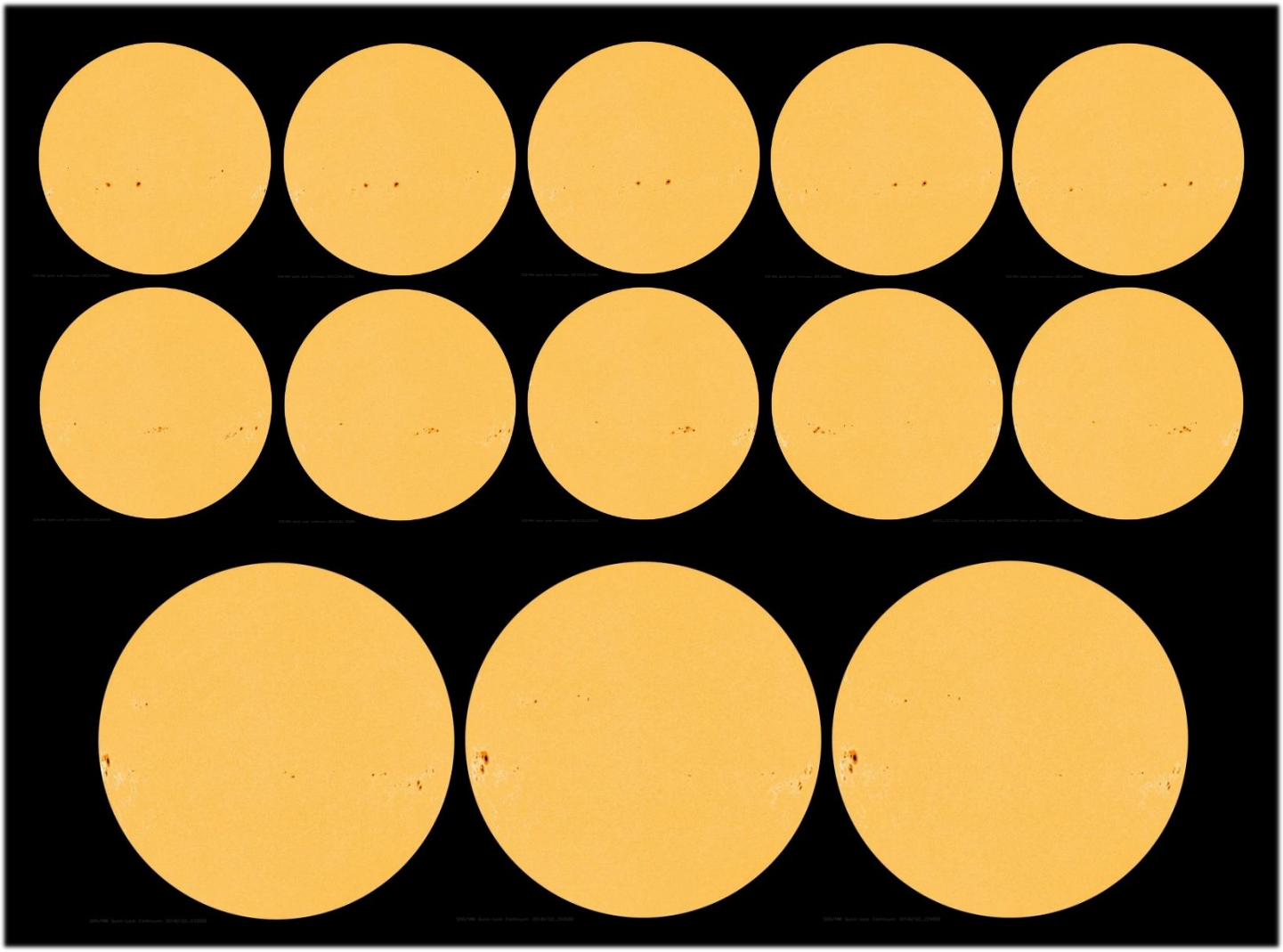


Images courtesy SOHO (NASA & ESA) and the Royal Swedish Academy of Sciences.

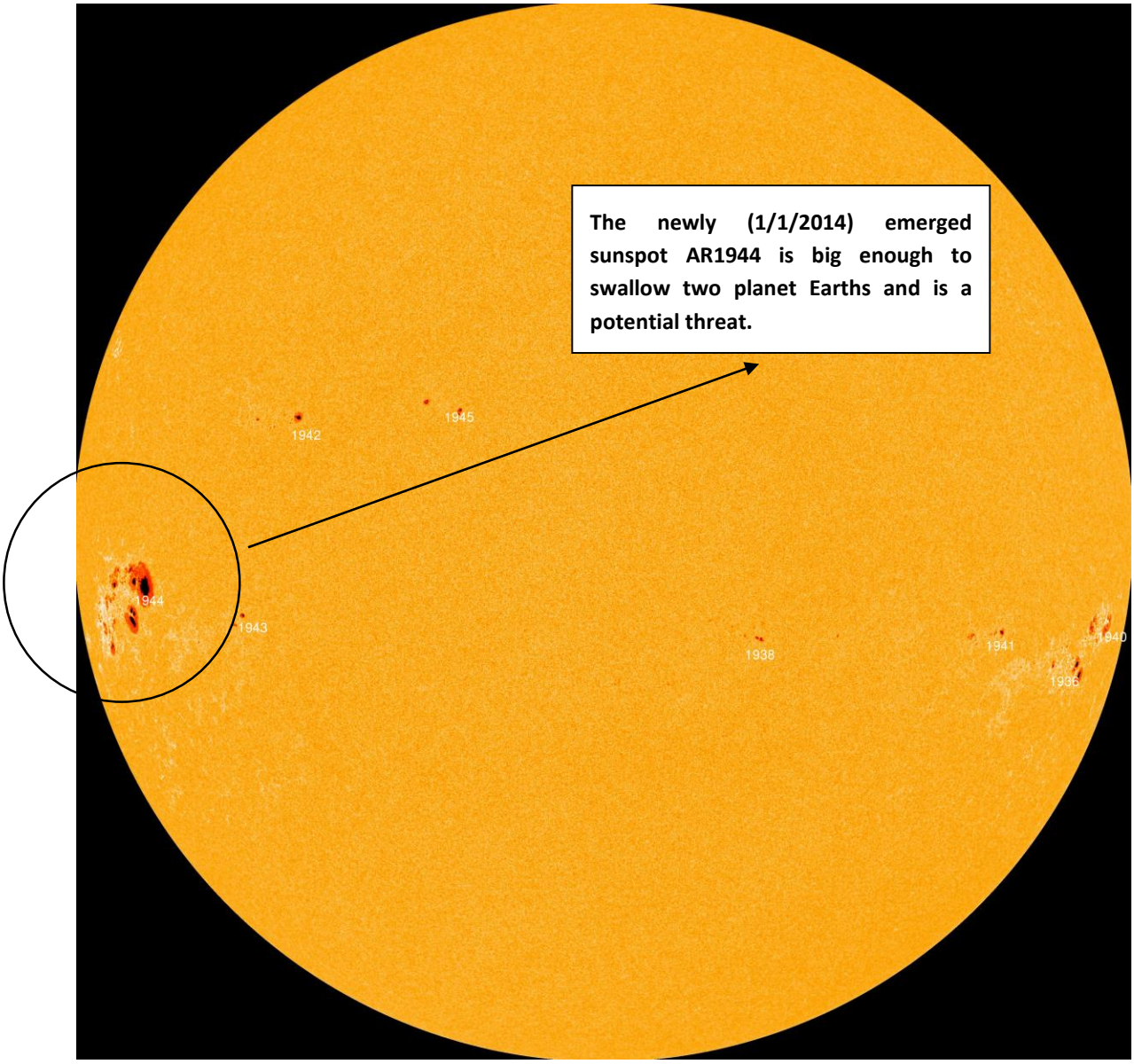
CHAPTER I – SUNSPOT REGIONS

Collecting Data

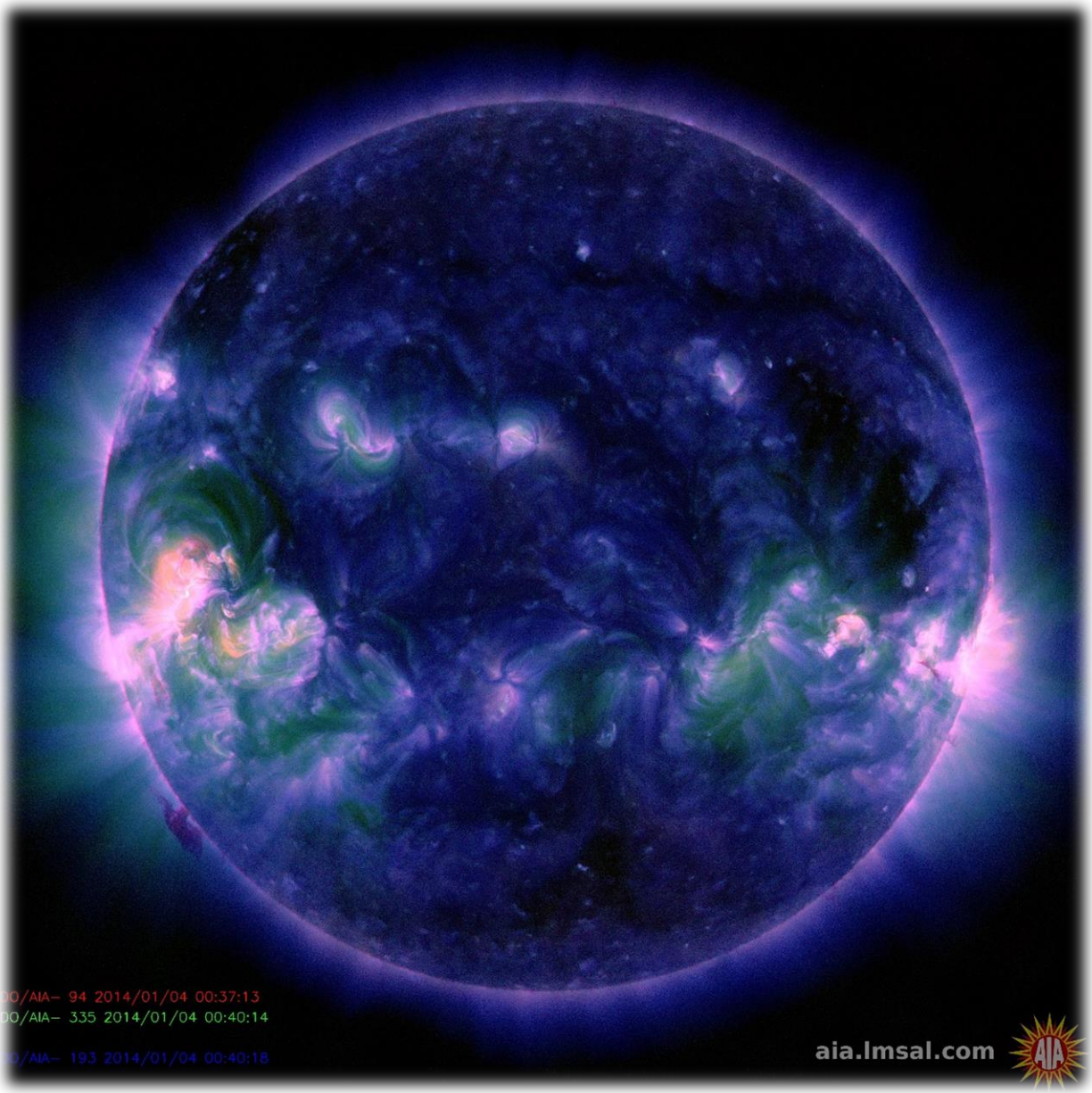
In order to provide the best weather prediction, our team has spent the last week gathering data and observing the Sun. In the pictures below you can see how the sunspots on the surface of the star have evolved in the 12/24/2013-1/4/2014 timeframe. The first set of images below comes from the Helioseismic and Magnetic Imager instrument (HMI) of the Solar Dynamics Observatory (SDO).



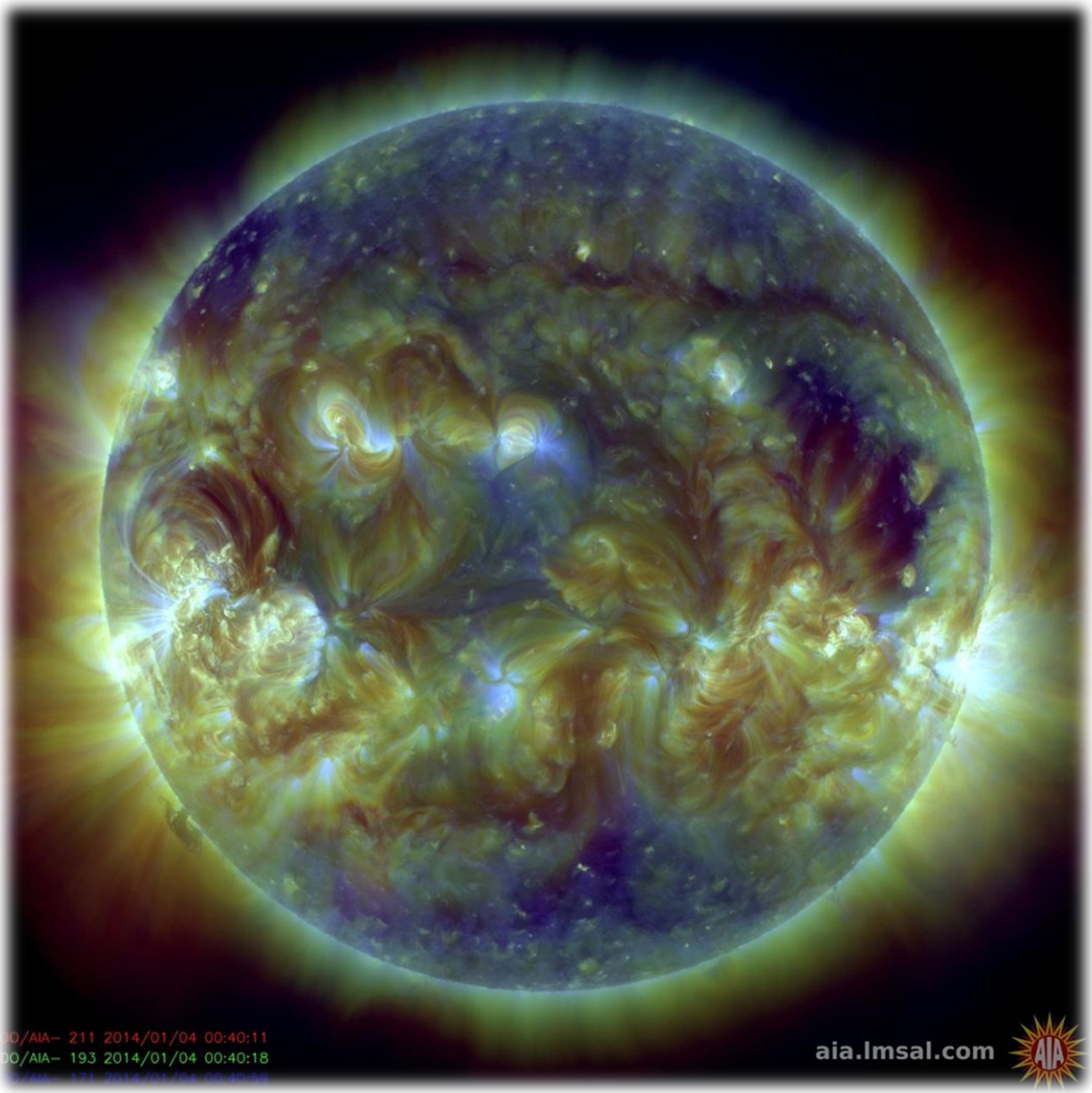
CHAPTER I – SUNSPOT REGIONS – THE SUN RIGHT NOW



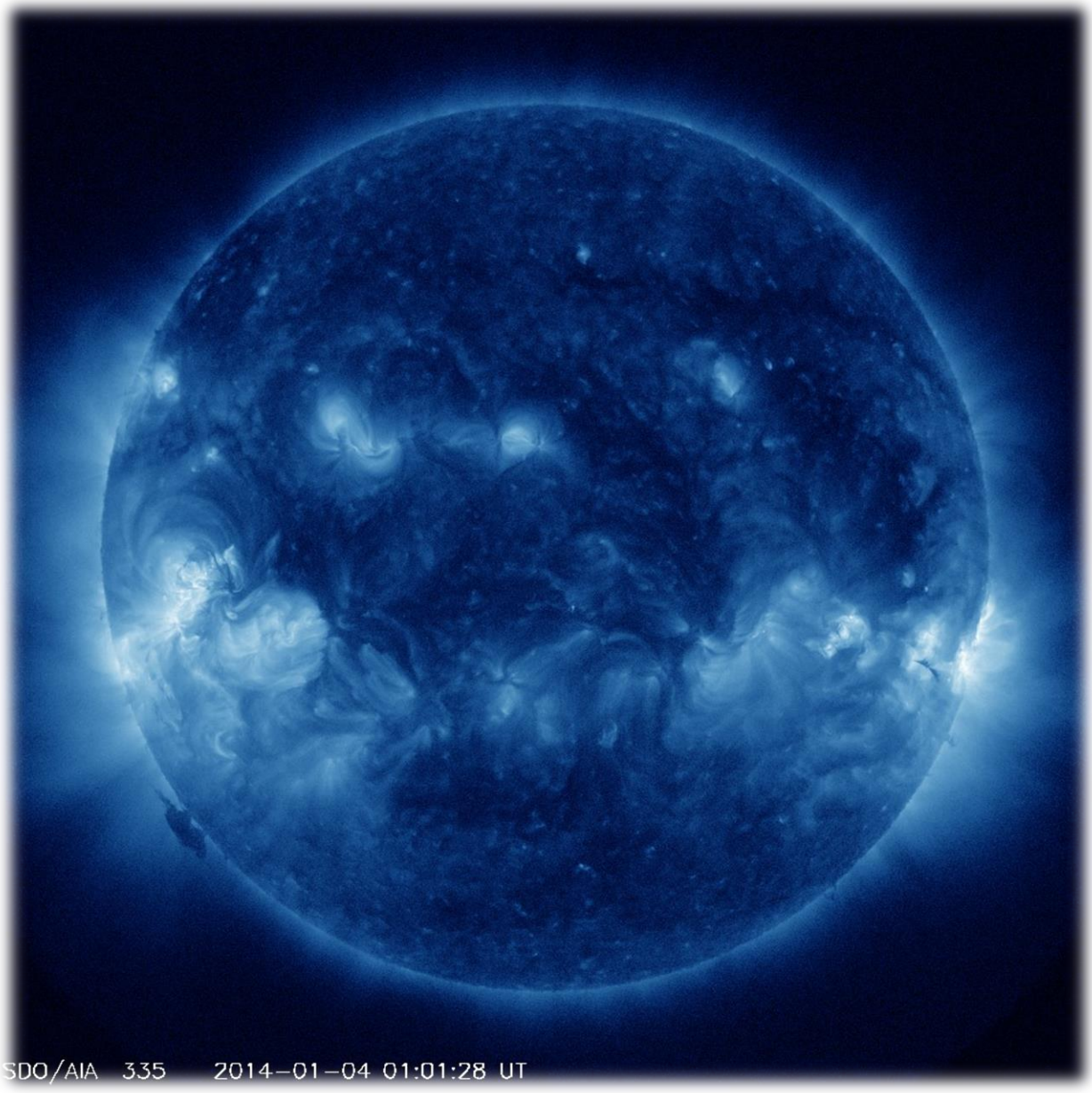
CHAPTER I – SUNSPOT REGIONS – THE SUN RIGHT NOW



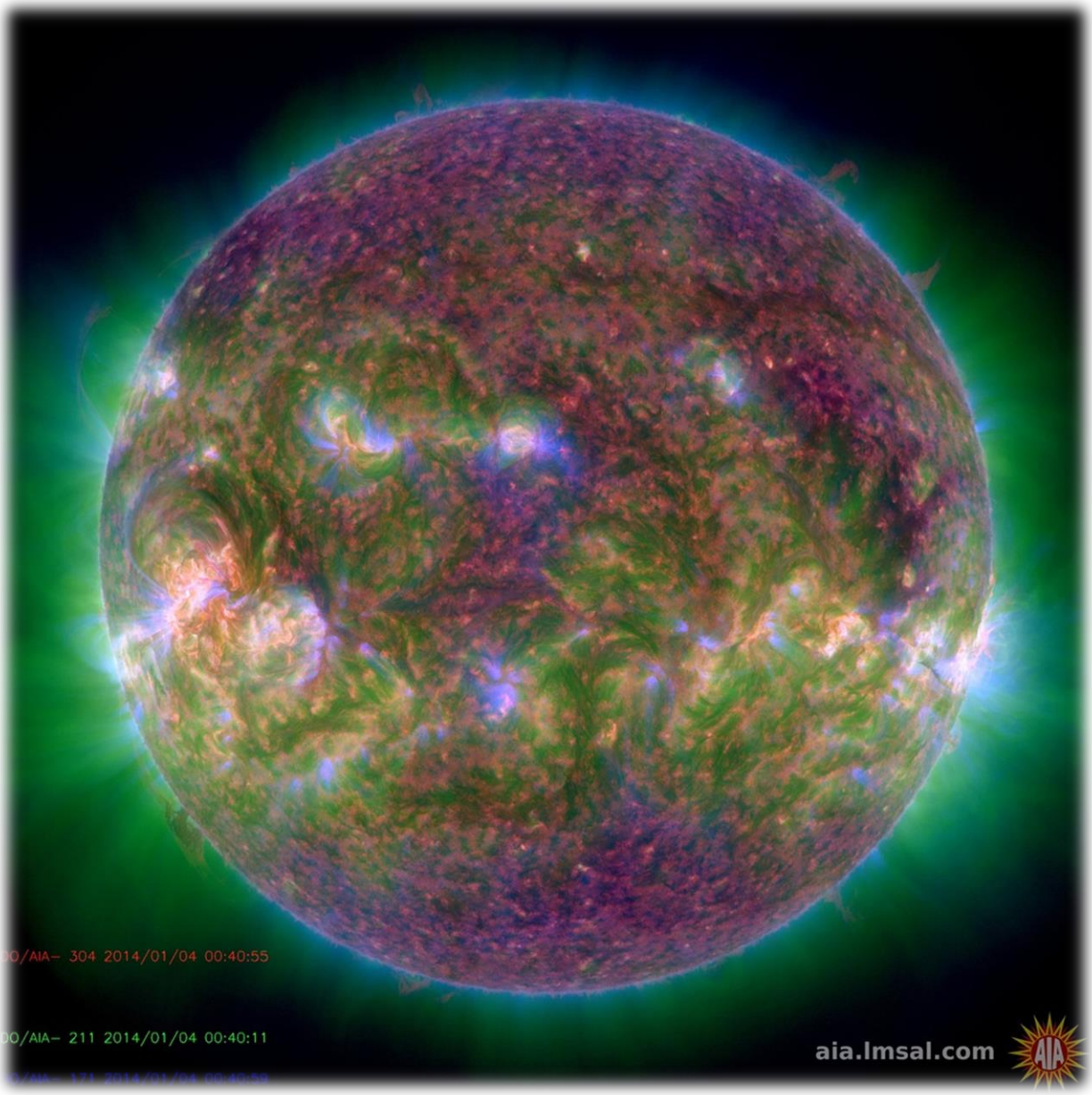
CHAPTER I – SUNSPOT REGIONS – THE SUN RIGHT NOW



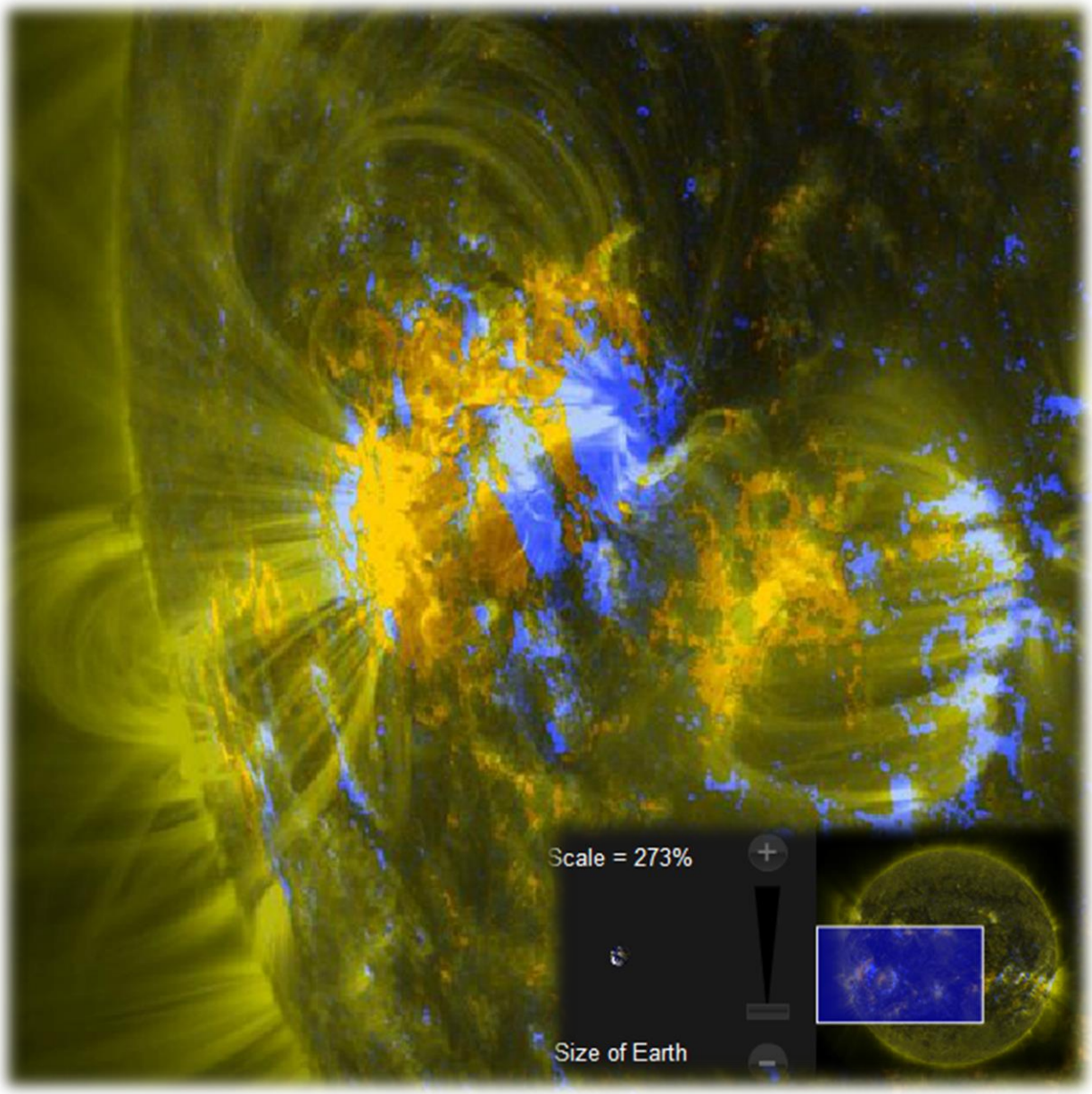
CHAPTER I – SUNSPOT REGIONS – THE SUN RIGHT NOW



CHAPTER I – SUNSPOT REGIONS – THE SUN RIGHT NOW



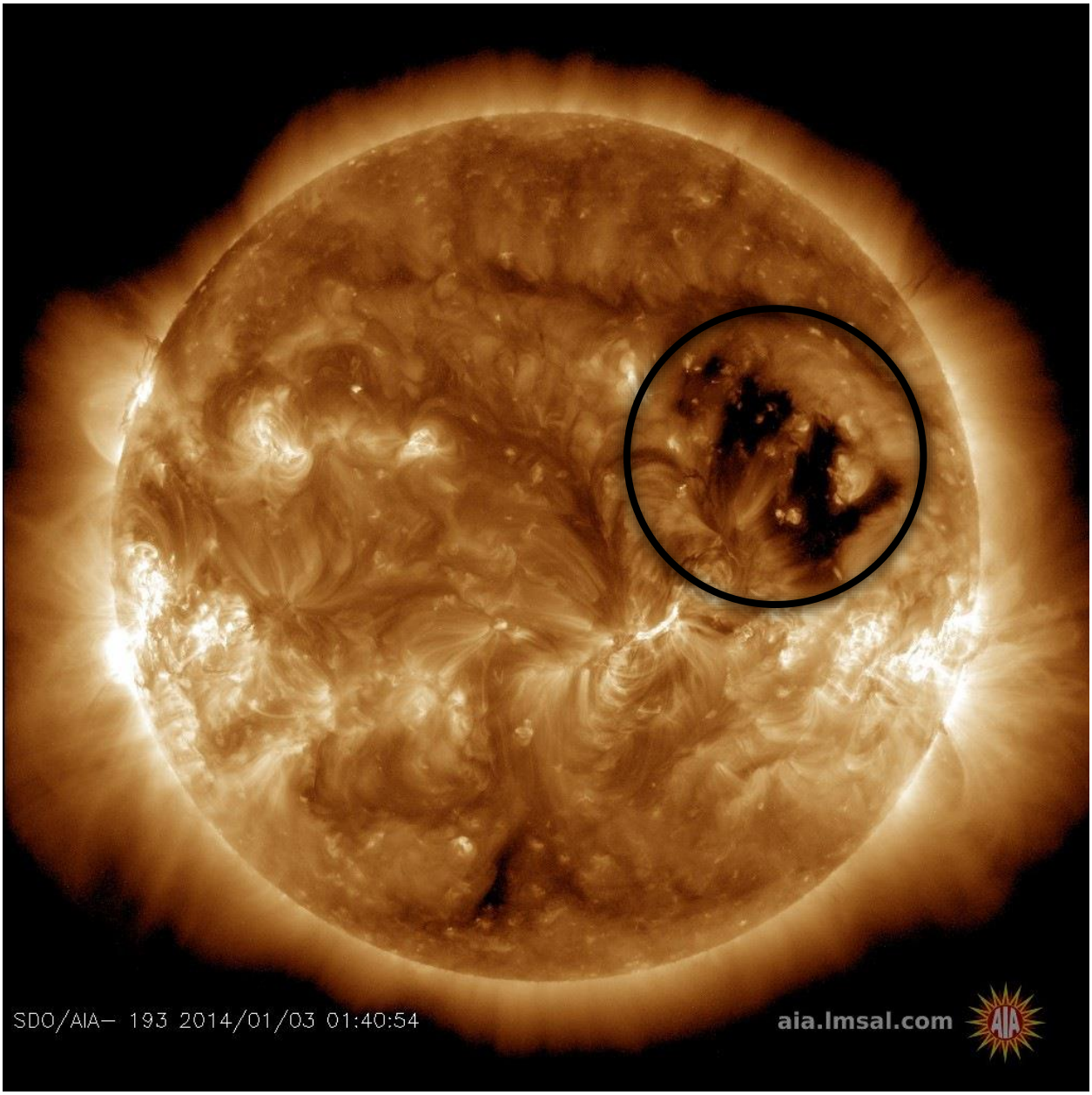
CHAPTER I – SUNSPOT REGIONS



Sunspot AR1944 - 'beta-gamma' magnetic field harbors energy for M-class solar flares. SDO/AIA161+HIM

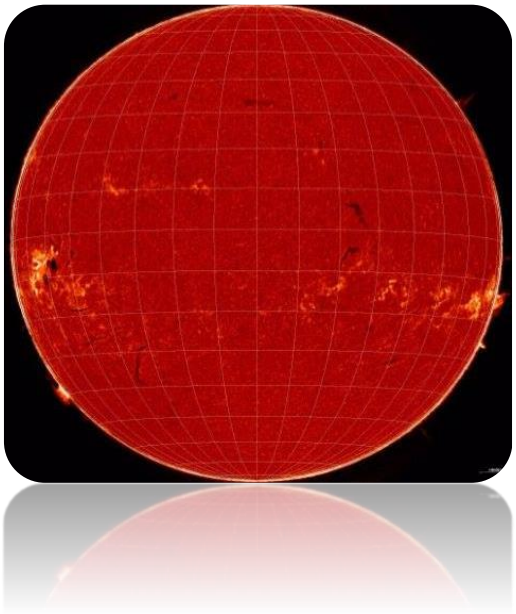
CHAPTER I – SUNSPOT REGIONS

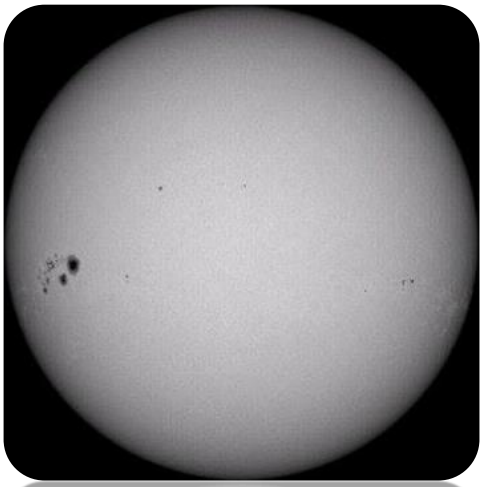
By analyzing the pictures above, we can see a number of active sunspots on the surface of the Sun. However, at a closer look, we might notice other phenomena too, including coronal loops and holes like the one in the image below.

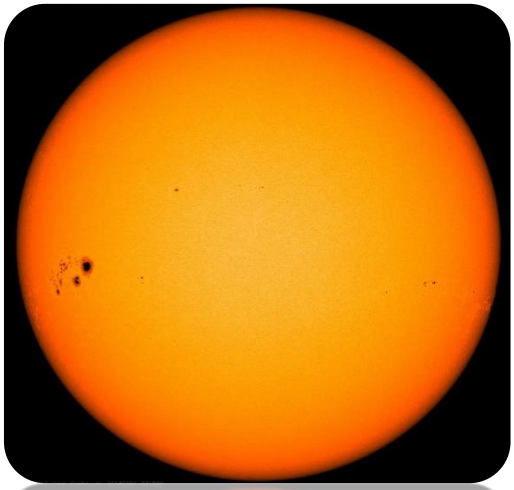


SUNSPOT REGIONS – DATA COLLECTION SHEET (1/4/2014)

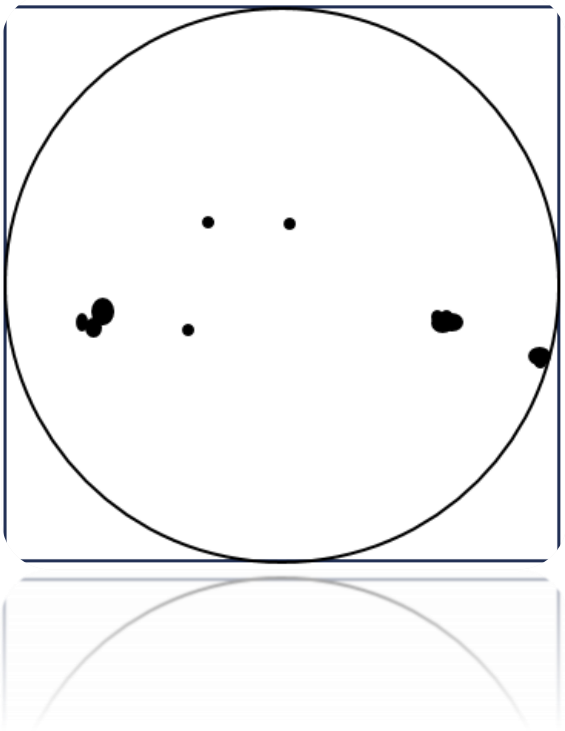
- By looking at the data provided by the Kanzelhohe Solar observatory, we can notice eight sunspots on the Sun's surface.
- AR1944, AR1943, AR1936, AR1938, AR1941 and AR1940 are all located slightly below the equator, while AR1952 and AR1945 are right above it.
- AR1944 is **twice the size of Earth**, being made up of more than a dozen dark cores. This means that the sunspot is visible from Earth as a blemish on the Sun's surface. All the other sunspots are Earth-sized.
- There are **six to eight** visible sunspots.
- There is a cluster of three sunspots near the right edge of the picture. For a better image, take a look at the SDO/HMI data presented before.



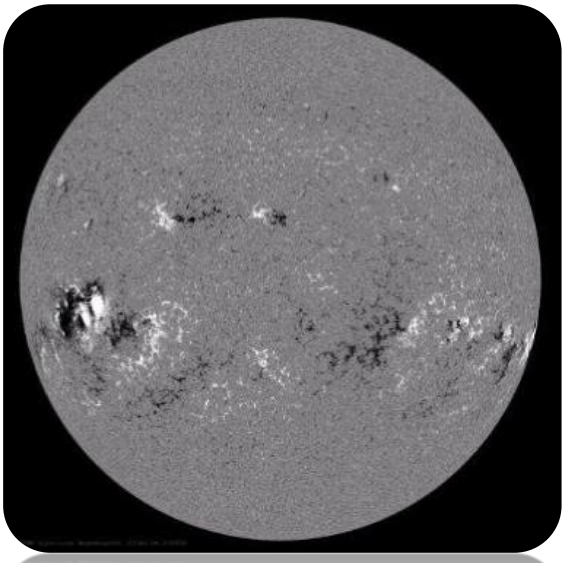




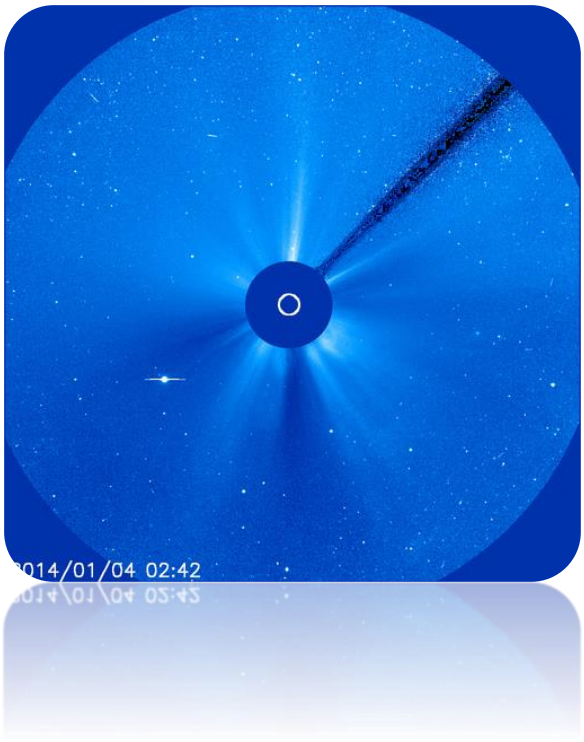
SUNSPOT REGIONS – DATA COLLECTION SHEET (1/4/2014)



- On the HMI Magnetogram there are some areas where the white and black spots are clearly separated, as well as some areas where they are mixed together.
- The active places in the images provided by the Atmospheric Imagery Assembly are, in fact, influenced by the presence of sunspots. Therefore, it is easy to understand why most of them occur near the dark spots. Coronal holes, like the one shown before, are the primary source of the solar wind. They are open structures that allow charged particles to escape from the Sun. Together with the Solar Prominences and the Coronal Loops, they are part of the solar activity driven by the magnetic field and, consequently, related to the sunspots.



SUNSPOT REGIONS – DATA COLLECTION SHEET (1/4/2014)



- There are no important Coronal Mass Ejections visible in the images provided by SOHO. However, we can notice solar activity in the lower left and upper right parts of the Sun.
- The particles reach Earth in one to four days.
- There is no significant halo effect. This means that the Earth is not in danger.

Do sunspot regions exist today that could be a source of solar storms?

The answer is yes! That would be AR1944, the newly emerged giant sunspot. The sunspot has a 'beta-gamma' magnetic field that harbors energy for strong eruptions. Forecasters estimate a 75% chance of M-flares and 30% for X-flares. Luckily, the effects would not be *that* devastating, thanks to the fact that the sunspot is not currently facing Earth. Even so, a blast from AR1944 could produce radio blackouts and geomagnetic activity.

AR1944 visible on the surface of the Sun

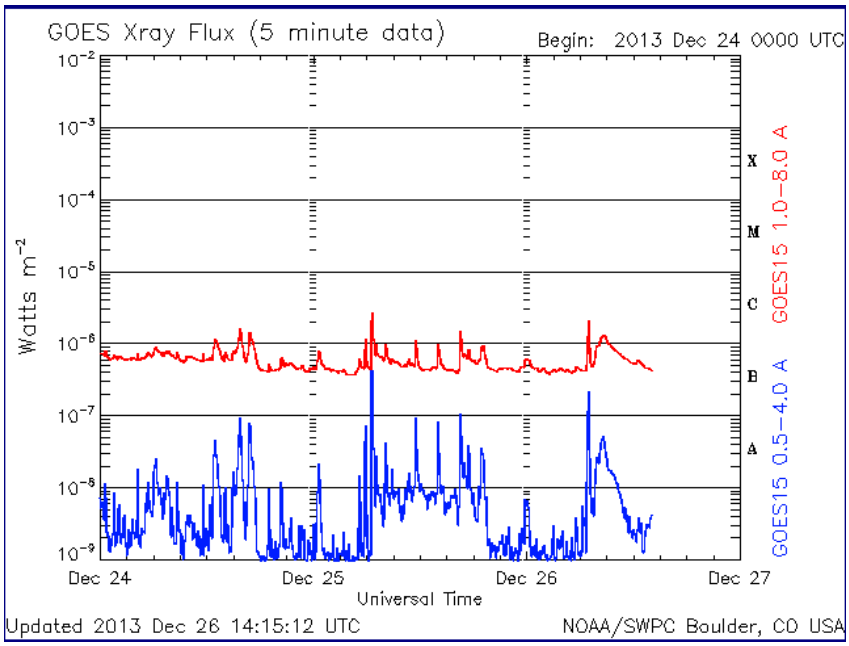
STORM SIGNALS

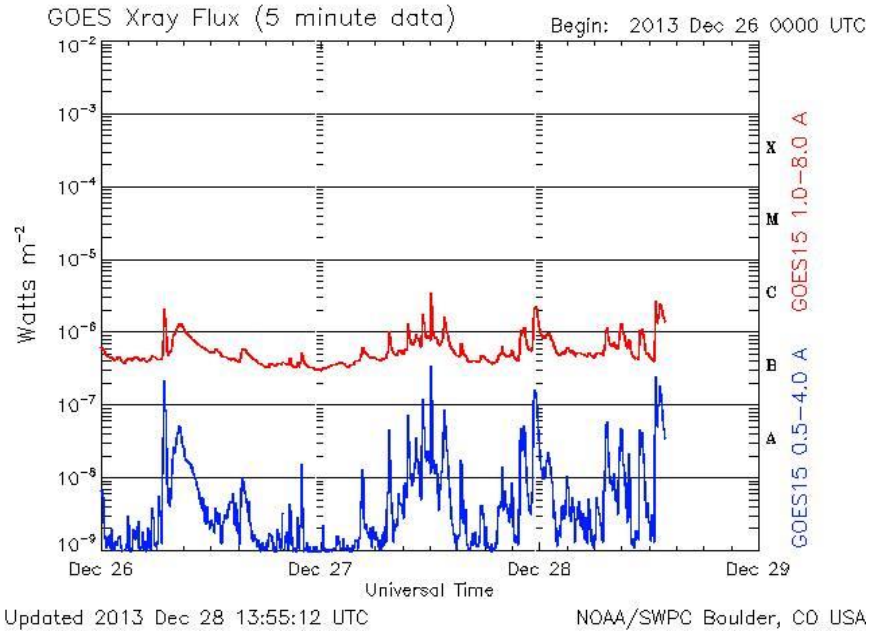
Introduction

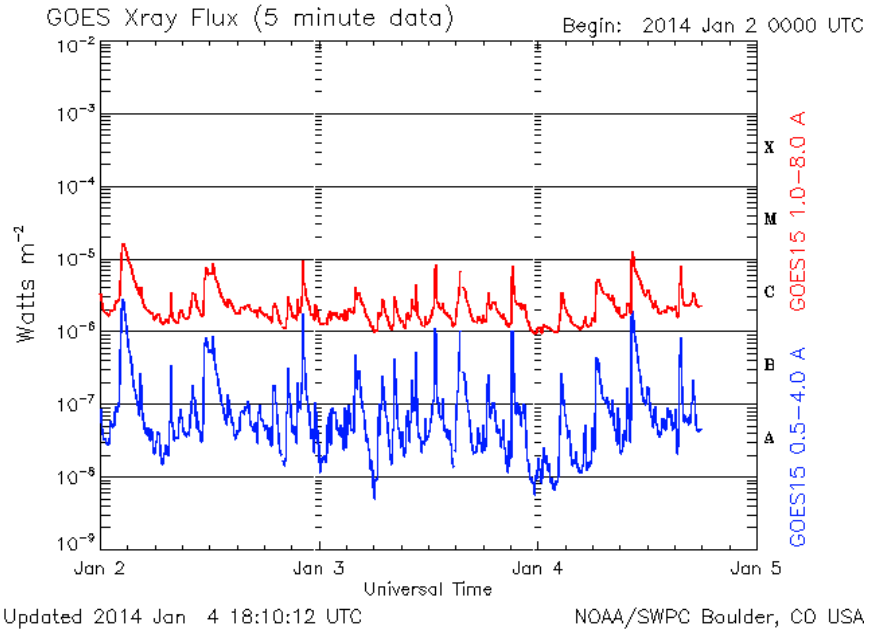
By studying the Sun's activity, scientists on Earth can tell exactly how the space weather is going to behave. Therefore, the observation and analysis of certain events that have been linked to powerful solar activity (storm signals) is of great importance in space weather forecasting.

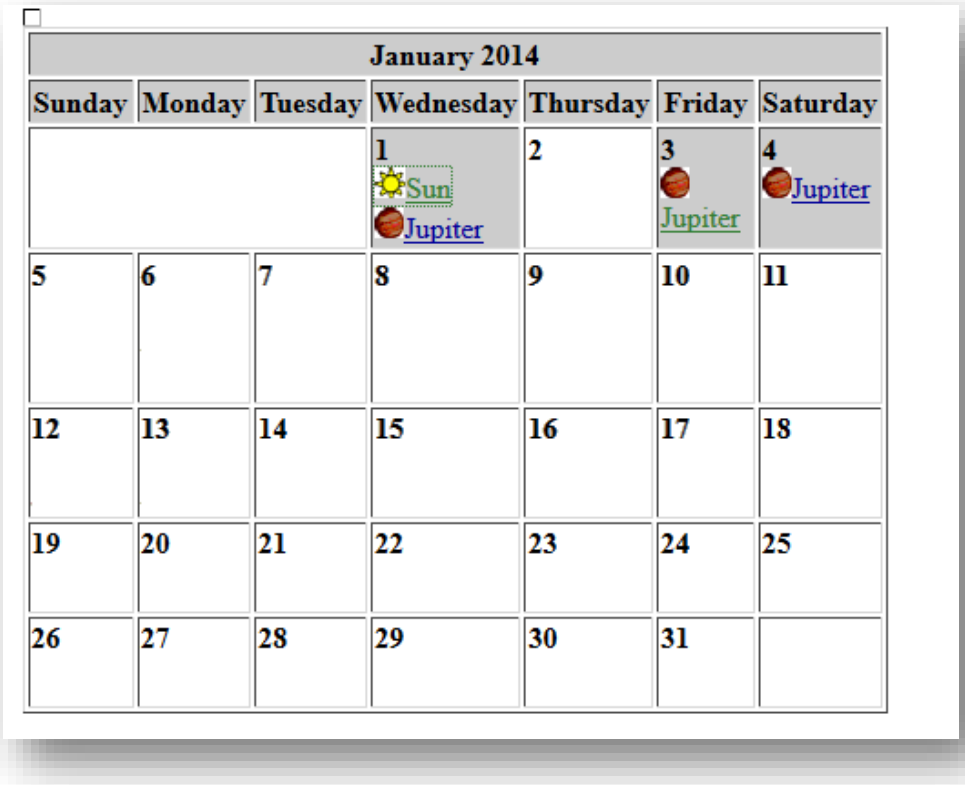
Data Collection

We started our research by collecting data from the RadioJove Archives and two GOES satellites (GOES 10 and GOES 12). Below you fill find the information recorded during the 12/24/2013-1/4/2014 timeframe.



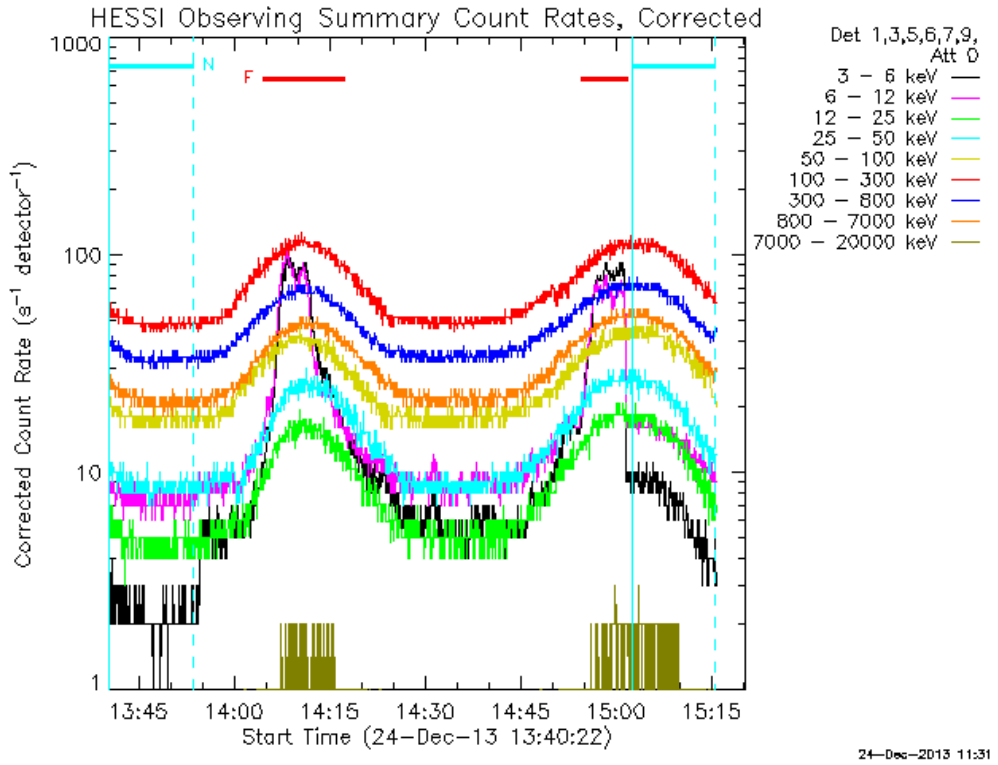

GOES Xray Flux (5 minute data)
Begin: 2013 Dec 26 0000 UTC
Watts m-2
GOES15 1.0–8.0 A
GOES15 0.5–4.0 A
X
M
C
B
A
Dec 26
Dec 27
Dec 28
Dec 29
Universal Time
Updated 2013 Dec 28 13:55:12 UTC
NOAA/SWPC Boulder, CO USA

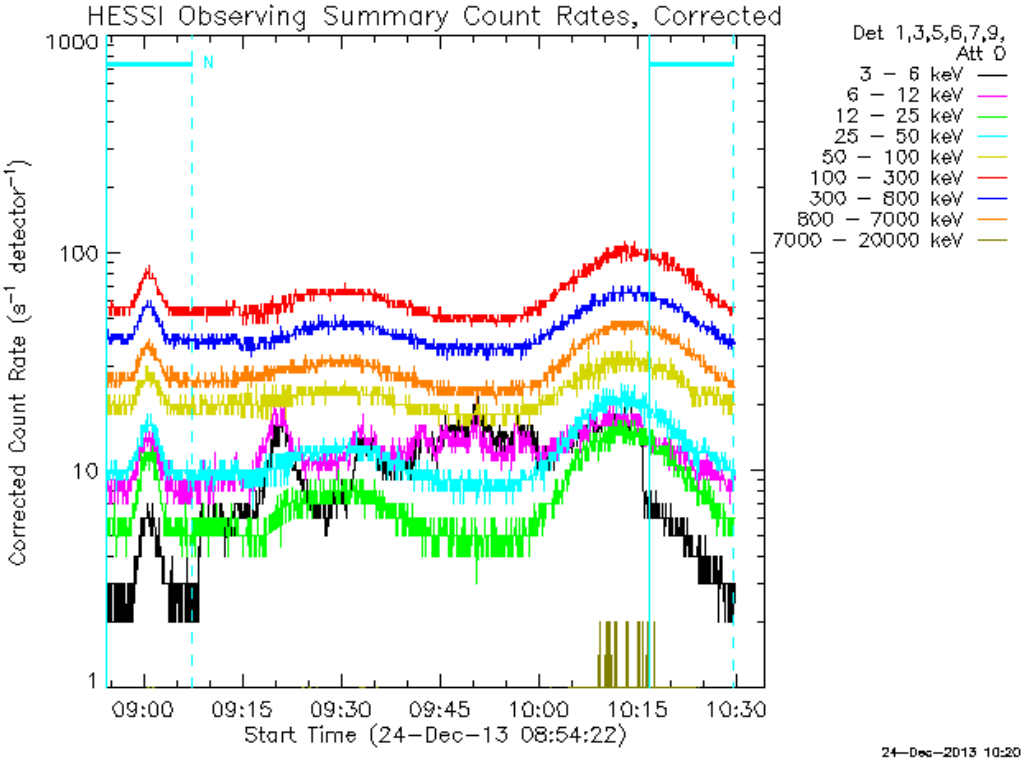

GOES Xray Flux (5 minute data)
Begin: 2014 Jan 2 0000 UTC
Watts m-2
GOES15 1.0–8.0 A
GOES15 0.5–4.0 A
X
M
C
B
A
Jan 2
Jan 3
Jan 4
Jan 5
Universal Time
Updated 2014 Jan 4 18:10:12 UTC
NOAA/SWPC Boulder, CO USA

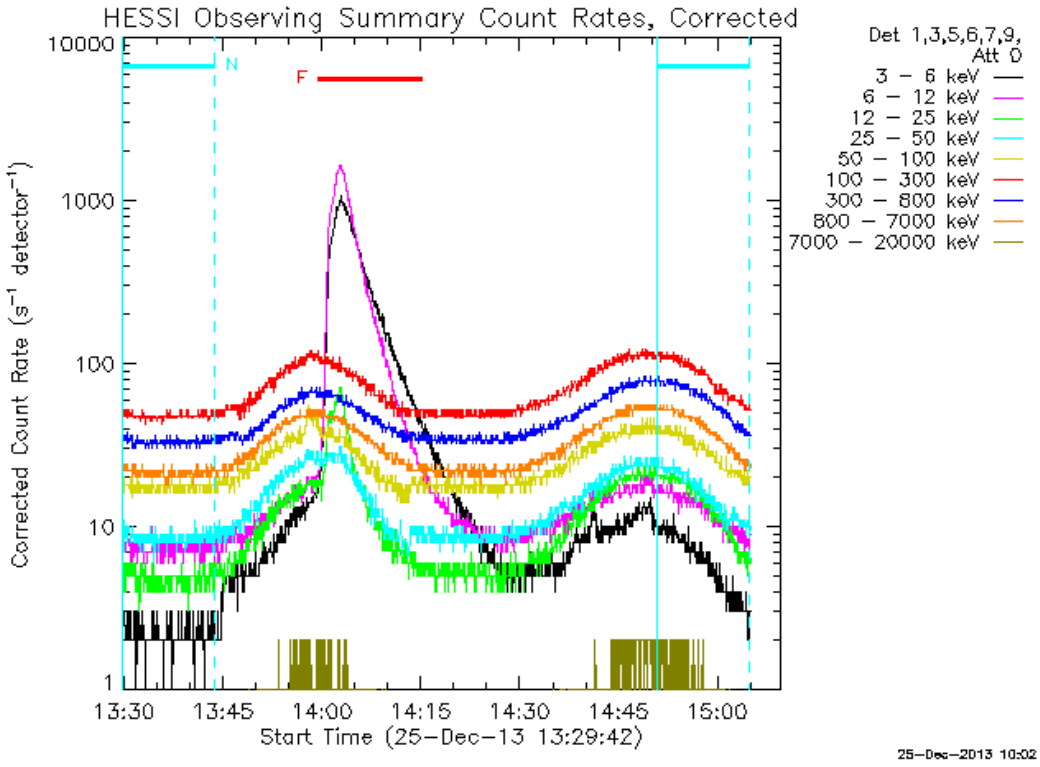


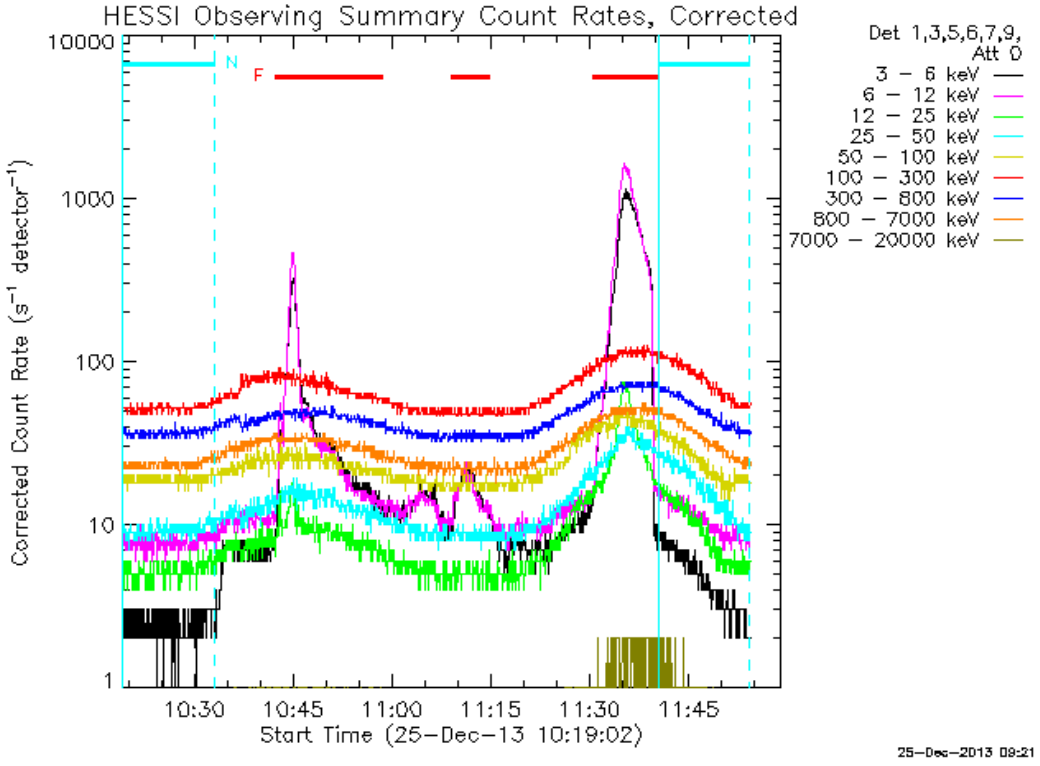
January 2014						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 Sun Jupiter	2	3 Jupiter	4 Jupiter
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

By studying the data above, we can see that neither RadioJove nor the GOES satellites have detected significant solar events. However, this does not mean that the Earth is safe from a solar storm. In spite of the fact that the event which occurred on the first of January does not pose a threat, it could very well be a sign of an upcoming stronger storm. Before moving on to the data collection sheet, we are going to analyze a few more sources.


HESSI Observing Summary Count Rates, Corrected
Det 1,3,5,6,7,9,
Att 0
3 – 6 keV
6 – 12 keV
12 – 25 keV
25 – 50 keV
50 – 100 keV
100 – 300 keV
300 – 800 keV
800 – 7000 keV
7000 – 20000 keV
N
F
Corrected Count Rate (s⁻¹ detector⁻¹)
1000
100
10
1
13:45
14:00
14:15
14:30
14:45
15:00
15:15
Start Time (24–Dec–13 13:40:22)
24–Dec–2013 11:31


HESSI Observing Summary Count Rates, Corrected
Det 1,3,5,6,7,9,
Att 0
3 – 6 keV
6 – 12 keV
12 – 25 keV
25 – 50 keV
50 – 100 keV
100 – 300 keV
300 – 800 keV
800 – 7000 keV
7000 – 20000 keV
N
Corrected Count Rate (s⁻¹ detector⁻¹)
1000
100
10
1
09:00
09:15
09:30
09:45
10:00
10:15
10:30
Start Time (24–Dec–13 08:54:22)
24–Dec–2013 10:20


HESSI Observing Summary Count Rates, Corrected
Det 1,3,5,6,7,9,
Att 0
3 – 6 keV
6 – 12 keV
12 – 25 keV
25 – 50 keV
50 – 100 keV
100 – 300 keV
300 – 800 keV
800 – 7000 keV
7000 – 20000 keV
N
F
Corrected Count Rate (s^{-1} detector^{-1})
10000
1000
100
10
1
13:30
13:45
14:00
14:15
14:30
14:45
15:00
Start Time (25–Dec–13 13:29:42)
25–Dec–2013 10:02

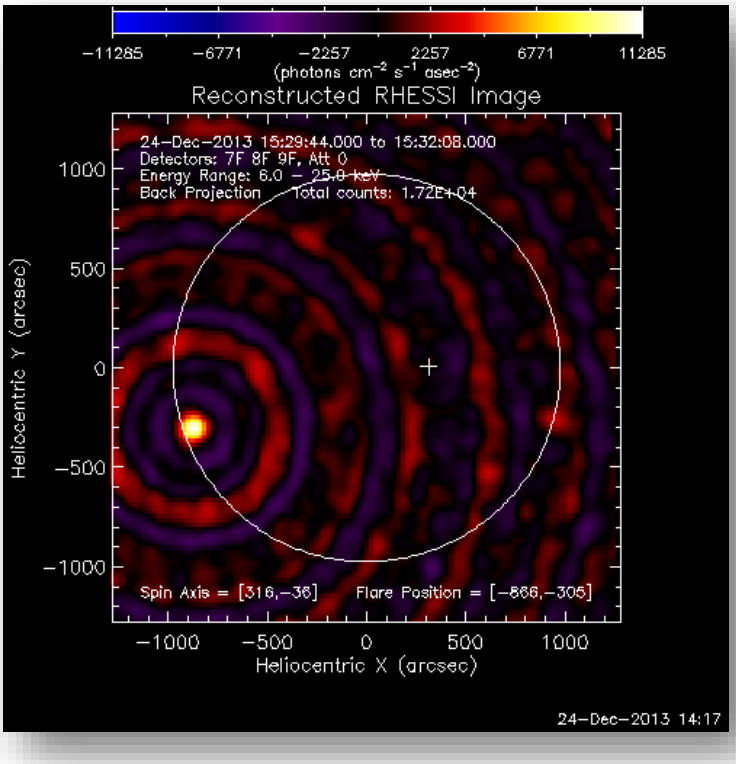

HESSI Observing Summary Count Rates, Corrected
Det 1,3,5,6,7,9,
Att 0
3 – 6 keV
6 – 12 keV
12 – 25 keV
25 – 50 keV
50 – 100 keV
100 – 300 keV
300 – 800 keV
800 – 7000 keV
7000 – 20000 keV
N
F
Corrected Count Rate (s^{-1} detector^{-1})
10000
1000
100
10
1
10:30
10:45
11:00
11:15
11:30
11:45
Start Time (25–Dec–13 10:19:02)
25–Dec–2013 09:21

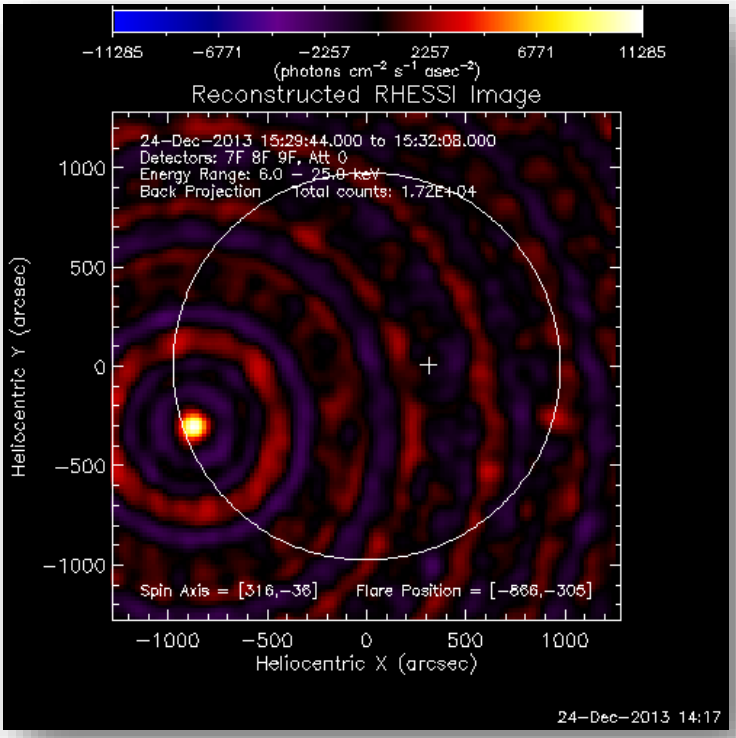
CHAPTER II – STORM SIGNALS

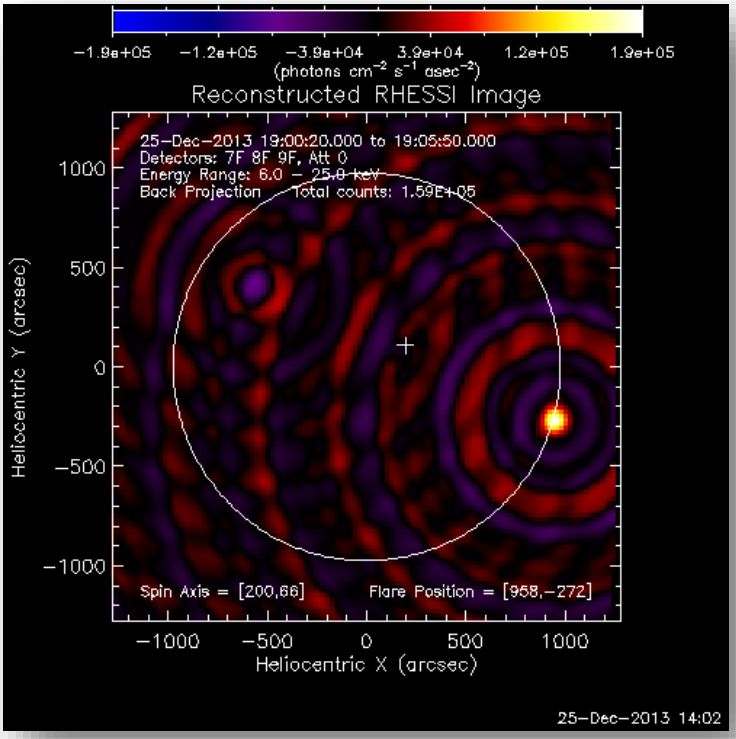
The sudden increase of the lowest energy bands indicate reduced scale solar flares. The red horizontal bar points out that the automatic algorithm has discovered a solar flare.

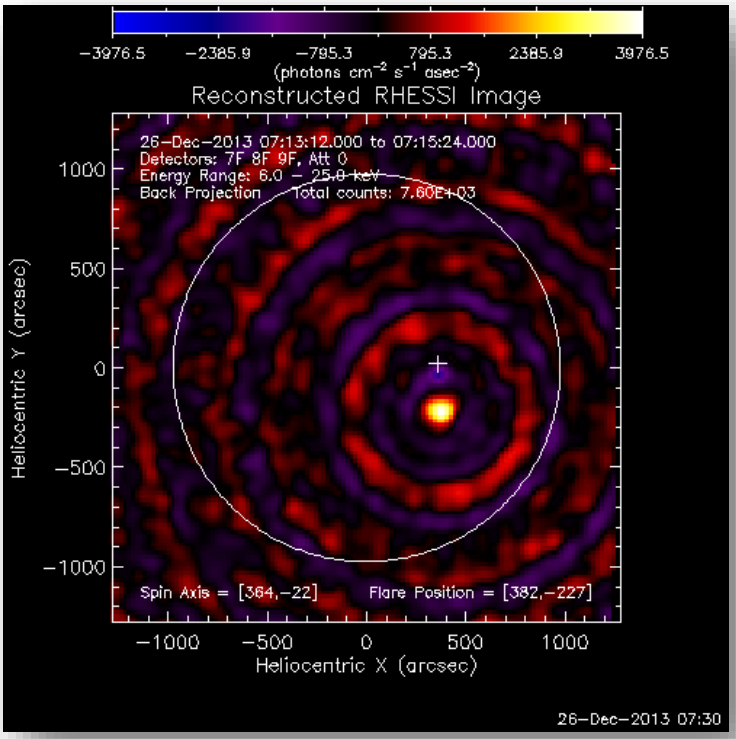
The horizontal orange bar shows an anomaly which has influenced the satellite's analysis. The disturbance is caused by the satellite passing through the South Atlantic Anomaly. The horizontal cyan bar indicates that the satellite is covered by the Earth's shadow and cannot properly observe the Sun.

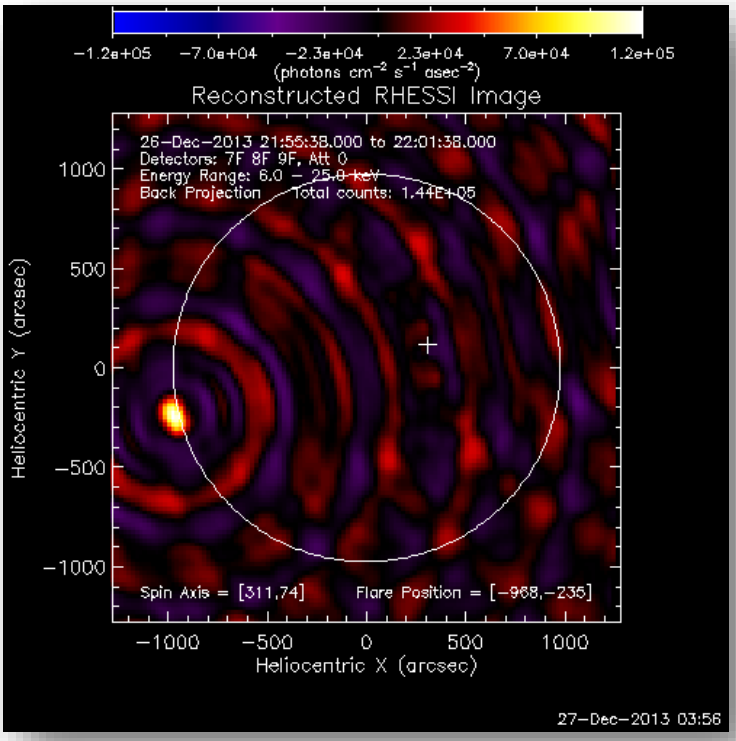
The following data is taken by the RHESSI satellite and can provide information in regards to possible upcoming solar storms.




−11285 −6771 −2257 2257 6771 11285
(photons cm^{-2} s^{-1} asec^{-2})
Reconstructed RHESSI Image
24-Dec-2013 15:29:44.000 to 15:32:08.000
Detectors: 7F 8F 9F, Att 0
Energy Range: 6.0 – 25.0 keV
Back Projection Total counts: 1.72E+04
Spin Axis = [316,-36] Flare Position = [-866,-305]
Heliocentric Y (arcsec)
Heliocentric X (arcsec)
1000
500
0
−500
−1000
24-Dec-2013 14:17


−1.9e+05 −1.2e+05 −3.9e+04 3.9e+04 1.2e+05 1.9e+05
(photons cm^{-2} s^{-1} asec^{-2})
Reconstructed RHESSI Image
25-Dec-2013 19:00:20.000 to 19:05:50.000
Detectors: 7F 8F 9F, Att 0
Energy Range: 6.0 – 25.0 keV
Back Projection Total counts: 1.59E+05
Spin Axis = [200,66] Flare Position = [958,-272]
Heliocentric Y (arcsec)
Heliocentric X (arcsec)
1000
500
0
−500
−1000
25-Dec-2013 14:02

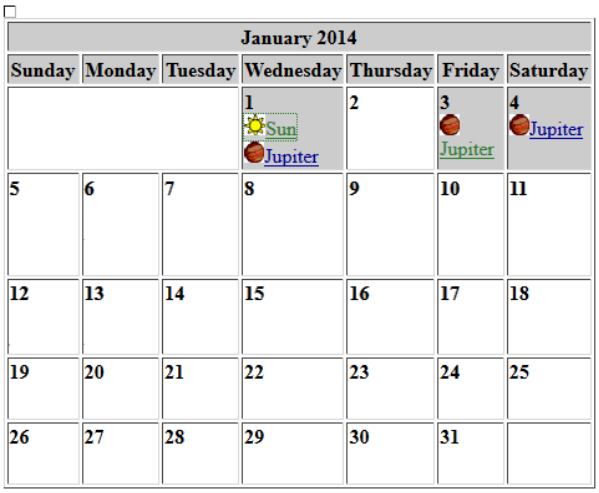

−3976.5 −2385.9 −795.3 795.3 2385.9 3976.5
(photons cm^{-2} s^{-1} asec^{-2})
Reconstructed RHESSI Image
26-Dec-2013 07:13:12.000 to 07:15:24.000
Detectors: 7F 8F 9F, Att 0
Energy Range: 6.0 – 25.0 keV
Back Projection Total counts: 7.60E+03
Spin Axis = [364,-22] Flare Position = [382,-227]
Heliocentric Y (arcsec)
Heliocentric X (arcsec)
1000
500
0
−500
−1000
26-Dec-2013 07:30


−1.2e+05 −7.0e+04 −2.3e+04 2.3e+04 7.0e+04 1.2e+05
(photons cm^{-2} s^{-1} asec^{-2})
Reconstructed RHESSI Image
26-Dec-2013 21:55:38.000 to 22:01:38.000
Detectors: 7F 8F 9F, Att 0
Energy Range: 6.0 – 25.0 keV
Back Projection Total counts: 1.44E+05
Spin Axis = [311,74] Flare Position = [-968,-235]
Heliocentric Y (arcsec)
Heliocentric X (arcsec)
1000
500
0
−500
−1000
27-Dec-2013 03:56

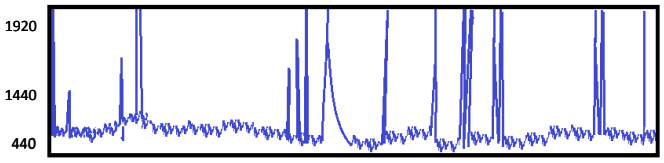
CHAPTER II – STORM SIGNALS – DATA COLLECTION SHEET

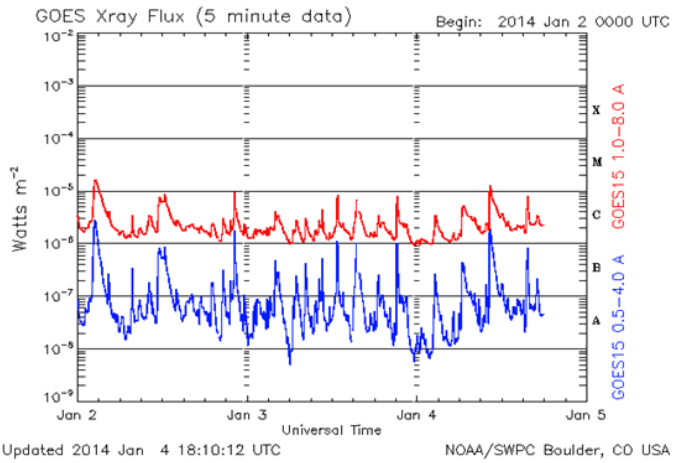
STORM SIGNALS – DATA COLLECTION SHEET (1/4/2014)

- According to the data in the Radio Jove Archives, there were no solar flares or coronal mass ejections today.
- Radio Jove did not register any X-Ray emissions since the January 1st Solar Storm and, therefore, we are unable to say if the emission level has changed. However, we can answer this question by using data from the GOES satellites, which shows that the level of emissions has increased.
- A drawing of the graph that indicated that a storm was emitted from the Sun can be found under the Radio Jove calendar on the right. (Click here for the original graph)
- While we do not believe that we are currently observing a solar storm, we are confident that a storm will occur within the next week, as predicted by the collected data.



January 2014						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
			1 Sun Jupiter	2	3 Jupiter	4 Jupiter
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	





CHAPTER II – STORM SIGNALS – DATA COLLECTION SHEET

STORM SIGNALS – DATA COLLECTION SHEET (1/4/2014)

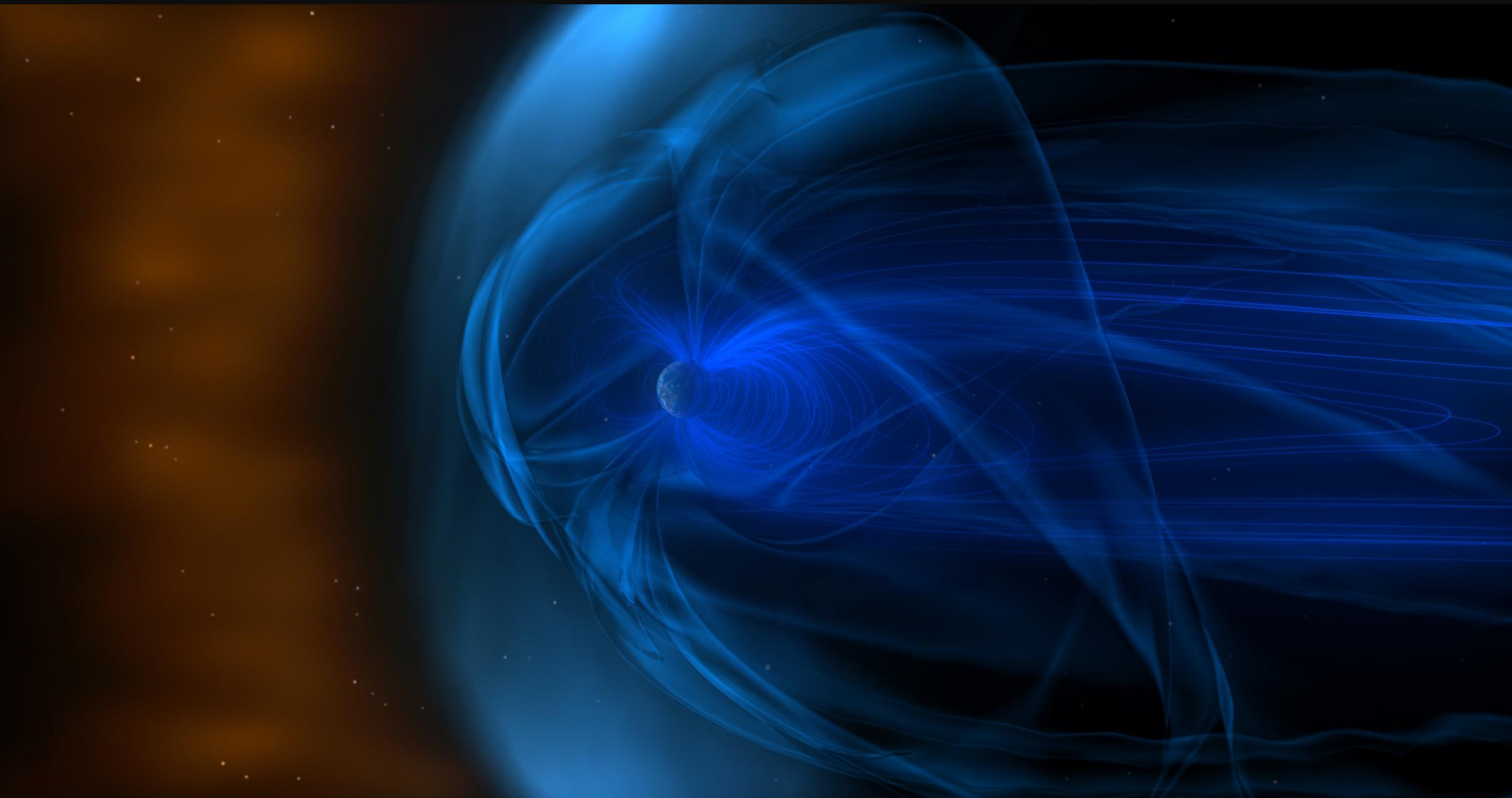
- The level of X-Ray emissions has been increasing intensely in the last week, which may be as sign of an approaching solar storm.
  By looking at the graph, we can see that the intensity of the X-Ray emissions has suffered a variation between the 10^{-6} Watts m^{-2} - 10^{-5} Watts $^{m-2}$ limits. This means that if a solar flare occurred it would have great intensity.

    - On the 2nd of January X-Ray emissions with intensities between the C and M levels occurred.
    - On the 3rd and 4th of January the X-Ray emissions were of C level.
    - On the 5th of January the occurring X-Ray emissions were of upper C / lower M intensity.

- Knowing that the solar storm takes around three days to reach the Earth and that the emission levels were between C and M, auroras will definitely be seen at lower latitudes in the next couple of days.

By analyzing the data provided by Radio Jove and the two GOES Satellites and by taking into account the Solar Storm which occurred on the first of January, we can say that there is a high chance of a solar storm happening in the near future. We believe that the high levels of solar activity are all signs of this and we estimate that the storm will hit Earth anytime between the 5th and the 8th of January.

MAGNETOSPHERE



MAGNETOSPHERE

= area of space surrounding an astronomical object and controlled by the object's magnetic field.

The Earth is the rocky planet with the strongest magnetosphere. Its shape is the result of being unceasingly blasted by the solar wind.

The Earth's magnetosphere is highly dynamic and will always react to changes in the Sun's activity.

One can think of the magnetosphere as a shield without which life on Earth would not have been possible. Deprived of its uninterrupted protection, development of life would have been impossible because of all the solar radiation.

Introduction

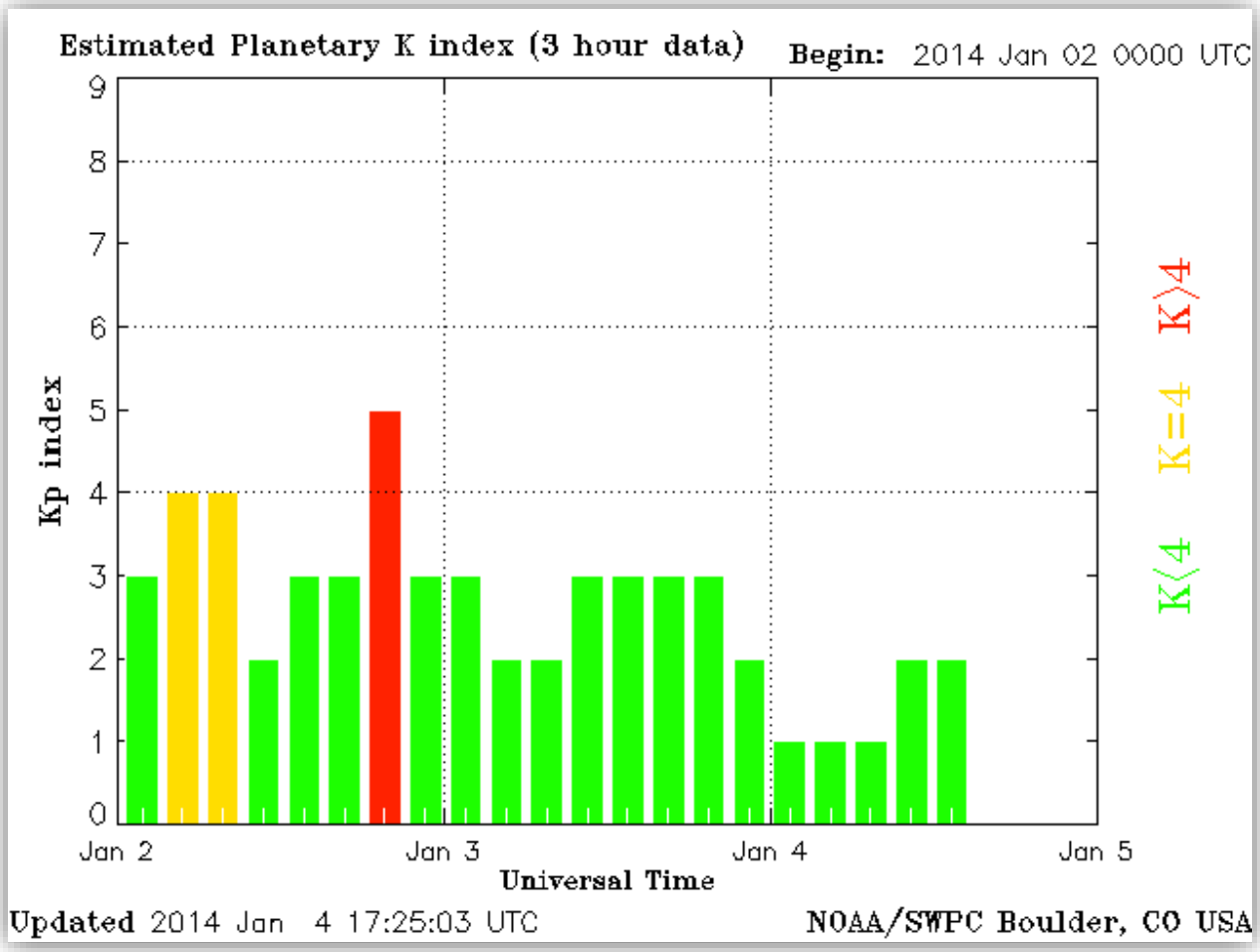
The next step in our space weather forecast is, without a doubt, the study of the Earth's very own shield: the magnetosphere. By analyzing changes in the way this protective layer generated by the Earth's magnetic field acts we can find out how the Sun's activity has affected our planet.

Collecting Data

In order to produce the best possible space weather forecast, our team has collected two different types of data. First, we wrote down the KP index (a way of measuring how disturbed the Earth's magnetic field is) of each day in our timeframe. Then, we analyzed the data provided by the ACE Magnetosphere Graph. With this, we were able to answer the questions in our data collection sheet and estimate how the space weather is going to evolve in the next week.

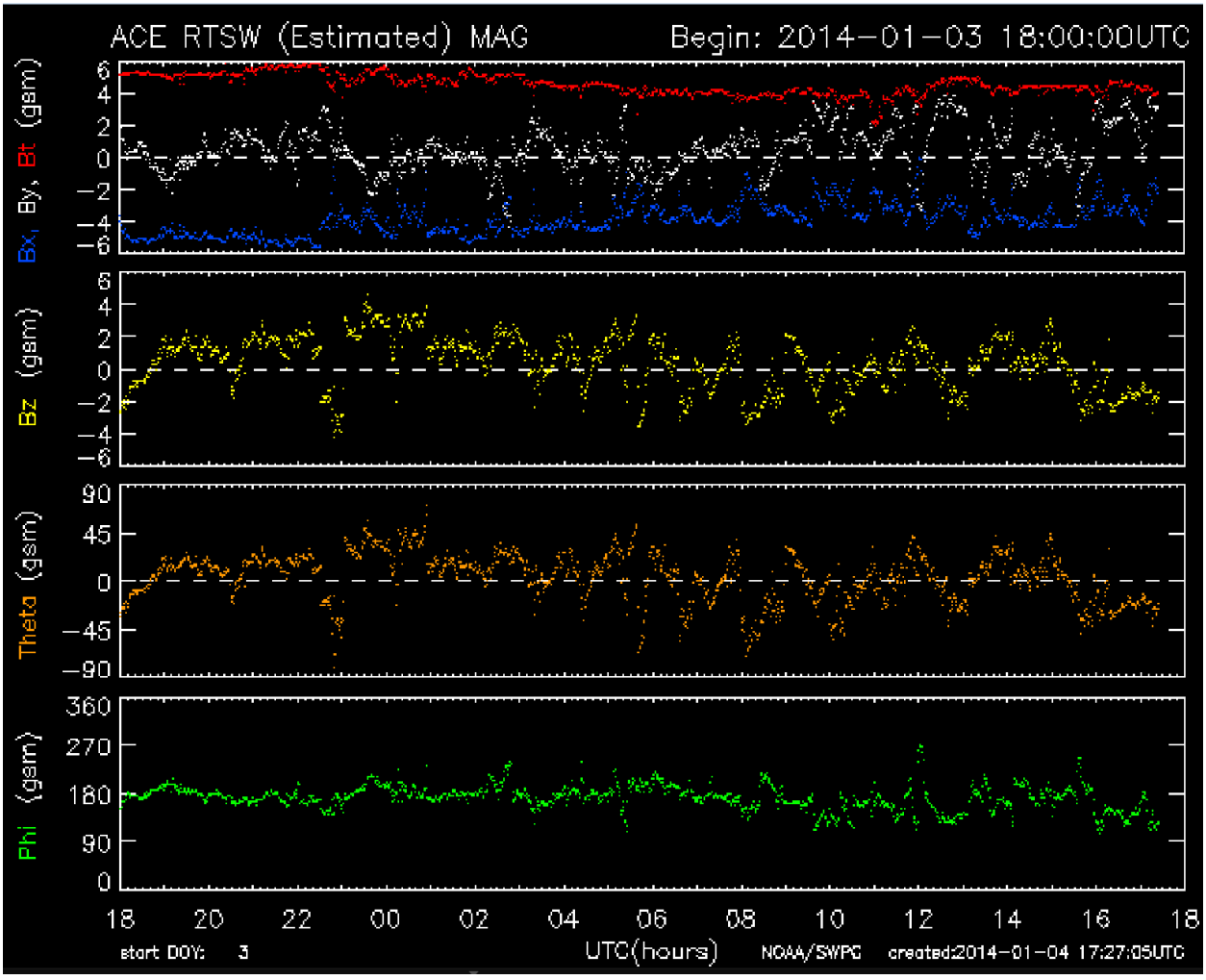
The Estimated Planetary K Index

The estimated planetary K index is obtained by averaging measurements taken by observatories from all around the world. By knowing this number, scientists and amateur astronomers can tell how much the Sun's activity has affected the Earth's magnetic field. Therefore, the Kp index gives people a way of knowing how powerful a solar storm was, based on its impact on our planet. (click on the picture to view the 12/30 – 2/1 graph)



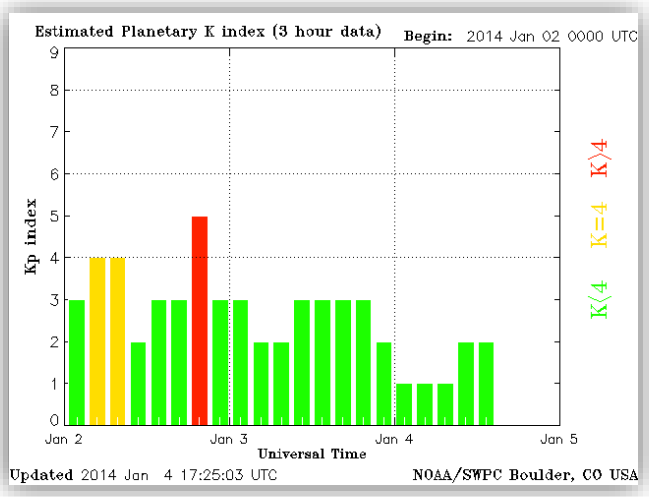
ACE Magnetosphere Graph

The instruments aboard the Advanced Composition Explorer satellite (observes particles of solar, interplanetary, interstellar, and galactic origins) can give us information on how the solar wind affects the Earth and its magnetosphere.

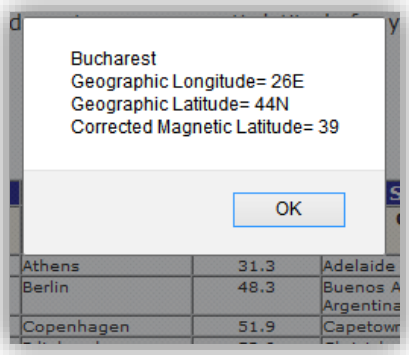


CHAPTER III – MAGNETOSPHERE – DATA COLLECTION SHEET

MAGNETOSPHERE – DATA COLLECTION SHEET (1/4/2014)



- This graph covers the 2nd, the 3rd and the 4th of January.
- The highest K index levels were 5 (on the 2nd of January), 3 (on the 3rd of January) and 2 (on the 4th of January).
- On January 2nd, the value of the Kp index had reached five, which indicates a G1 (Minor) Geomagnetic Storm. Fortunately, there were no values of seven or more, which means that there were no major magnetic disturbances and that a severe geomagnetic storm is unlikely to hit Earth anytime soon.
- Romania has a latitude of around 46° north and a longitude of 25° east. Its capital city, Bucharest, has a latitude of 44°N and a longitude of 26°E. The corrected geomagnetic latitude of Romania is 41° (39° for Bucharest).



- According to the Kp Auroral Map, the Kp level would have to be 9 for the auroras to be visible in our area. Therefore, they will only be visible in the case of an extremely severe geomagnetic storm.
- According to the Kp Auroral Map and the to the data collected from the graph, auroras will be visible south to the green line on January 2nd and south to the blue line on January 3rd and 4th.

CHAPTER III – MAGNETOSPHERE – DATA COLLECTION SHEET

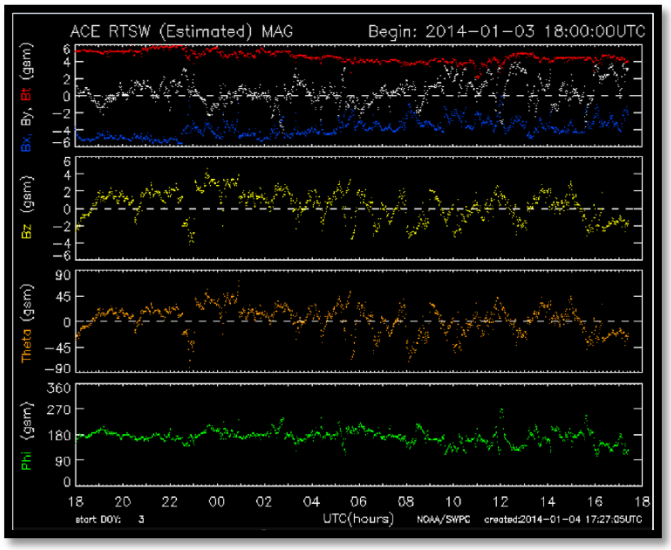
MAGNETOSPHERE – DATA COLLECTION SHEET (1/4/2014)

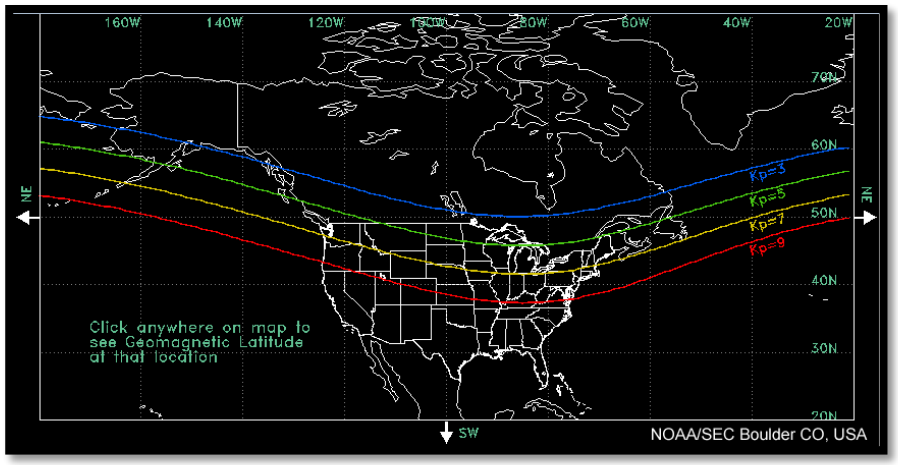
- The current level of storm activity (as shown by the Bz graph) oscillates between 2 and -4, indicating a low/medium level solar storm.

- The information regarding the geomagnetic storm arrived at the ACE satellite at around 22:00:00 UTC on the 3rd of January and at around 04:00:00 UTC on the 4th of January.

- Because of the satellite's position, the solar storm will arrive on Earth about one hour after reaching the satellite. Therefore, the storm will hit Earth at approximately 05:00:00 UTC on the 4th of January.

- After studying the data provided by the ACE satellite, we can say that there definitely was a major disturbance in Earth's magnetic field. As seen in the Bz graph, the levels changed from 2, 4 and 5 to almost -5 at around 23:30:00 UTC January 3rd.






AURORAS

Introduction

Auroras – mystical displays of light in the sky which have inspired countless myths and stories. What exactly are they? What causes them? Why are they only found in high latitude regions?

When solar wind hits the Earth, energetic charged particles (ions and electrons) collide with the atoms in the thermosphere. Auroras are the direct result of the oxygen and nitrogen emission which take place in the upper atmosphere. Their color is influenced by the element involved in the reaction. Red auroras are the least visible and are caused by atomic oxygen found at the highest point of the thermosphere. Green auroras are the most common type of aurora because of the high concentration of atomic oxygen at lower altitudes and our higher eye sensitivity in green. Yellow and pink are caused by a mix of red and green auroras, while the blue ones are caused by ionized molecular nitrogen. Another interesting detail it the fact that The Earth's magnetic field was found to be significantly disturbed near the auroras due to large electrical currents flowing up and down along the auroral features.

Data Collection

In conformity to the research strategy used in the other three chapters, our team has studied the evolution of the auroras during the 28th of December 2013 – 4th of January 2014 timeframe. By using the data provided by the NOAA POES plot and by the Kiruna All-Sky camera, we have been able answer all the questions in the Data Collection Sheet.

The Kiruna All-Sky Camera

Below you will find links which point to the data collected by our *Auroral Research* team from the Kiruna All-Sky camera.

12/28/2013 https://imageshack.com/a/GPgq/1

12/29/2013 https://imageshack.com/a/2Pgq/1

12/30/2013 https://imageshack.com/a/hPgq/1

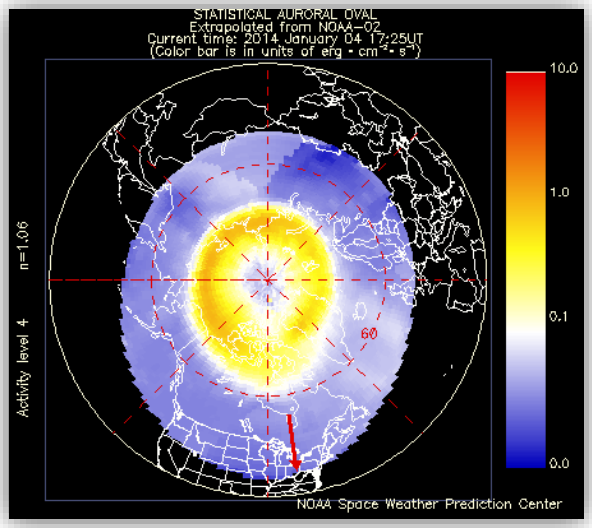
12/31/2013 https://imageshack.com/a/mPgq/1

01/01/2014 https://imageshack.com/a/mPgq/1

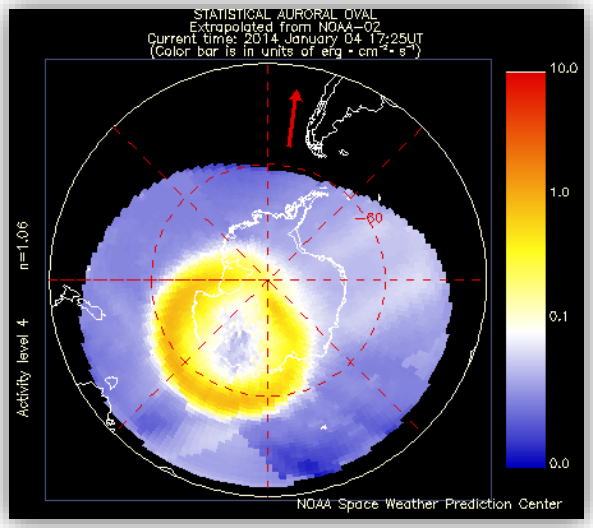
CHAPTER IV – AURORAS – DATA COLLECTION SHEET

AURORAS – DATA COLLECTION SHEET (1/4/2014)

- By studying the map on the right, we can say that the storm's intensity is low to moderate. According to the plot provided by NOAA, aurora activity is very low in the upper-central part of North America and in Russia. However, the activity in Greenland, Alaska, northern Canada and in the Scandinavian Peninsula is of moderate level. As auroras usually occur in ring-shaped areas circling Earth's magnetic poles, the intensity of the aurora gradually decreases with its expansion and distance from the poles.



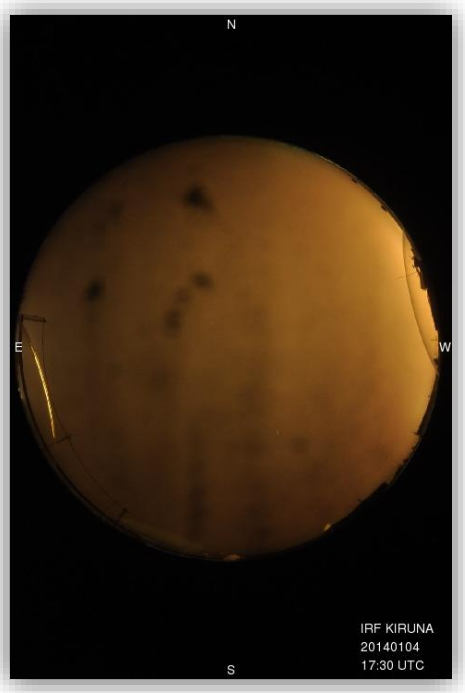
- The southernmost extent of the auroral activity is in the United States of America (Missouri). However, auroral activity there is very low and only significant during strong solar storms. Therefore, we can say that the southernmost extent of the auroral activity where the auroras are actually visible is somewhere around Hudson Bay, Canada.



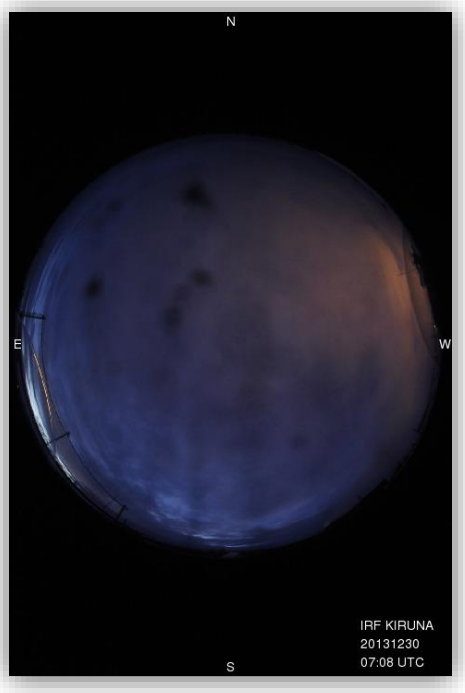
- Auroras can be seen anywhere around the arctic circle between Canada and the top states of the United States. Furthermore, they can be seen above the Scandinavian Peninsula and Russia (aurora borealis), but also in Australia, Antarctica and New Zealand (aurora australis).

CHAPTER IV – AURORAS – DATA COLLECTION SHEET

AURORAS – DATA COLLECTION SHEET (1/4/2014)



- The picture was taken at 2014-01-04; 17:30 UTC
- When studying the image caught by the Kiruna All-Sky camera on the 4th of January 2014 at 17:30 UTC, a brown-yellow gradient can be seen across the sky. This is, probably, caused by other light sources. By looking west, we can see a clouded area with a lighter shade, which (we hope) might be an aurora. Due to the reduced visibility, we cannot say for sure if there is little aurora activity or if there is no activity at all. For comparison, we have put another image caught by the same camera on 2013-12-30 during night-time.
- On 2014-1-24, as seen in the image taken by the Kiruna All-Sky camera, the auroral activity is low
- By looking at the data collected by our team, we can say that auroras have been seen in the last 24 hours (click here for a picture of the auras taken on the 3rd of January, © Tommy Eliassen).



RESULTS

After gathering and studying the data provided by all four research teams, we have been able to draw a number of conclusions and write our closing remarks.

The storm is coming. Maybe not today, maybe not even tomorrow, but one day it will happen, and that day is less than a week away. All the signs are there: a large number of sunspots on the surface of the Sun, X-Ray emission levels that keep getting higher and higher, disturbances in the Earth's magnetosphere. The presence of such a wide range of phenomena can only mean one thing. A solar storm is about to hit.

ABOUT US

Our team is made up of nine students from the 'Tudor Vianu' National Highschool of Computer Science (Romania). Everyone in our team is sixteen years old and has a great passion for everything involving science.

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Daria Donovetsky

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